Astrophysical signatures for axion(-like) particles

→ WIMPs

K. Zioutas

University of Patras

→ TAUP2005 *updated*

→ CERN + Patras *libraries*

ILIAS-CAST-CERN Axion Training

CERN / Geneve

30/11/2005

Stellar observations in the visible + theory on stellar evolution

↛ stars might possess atmospheres … that produce X-rays.

L.W. Acton, Magnetodynamic Phenomena in the Solar Atm. (**1996**) 3

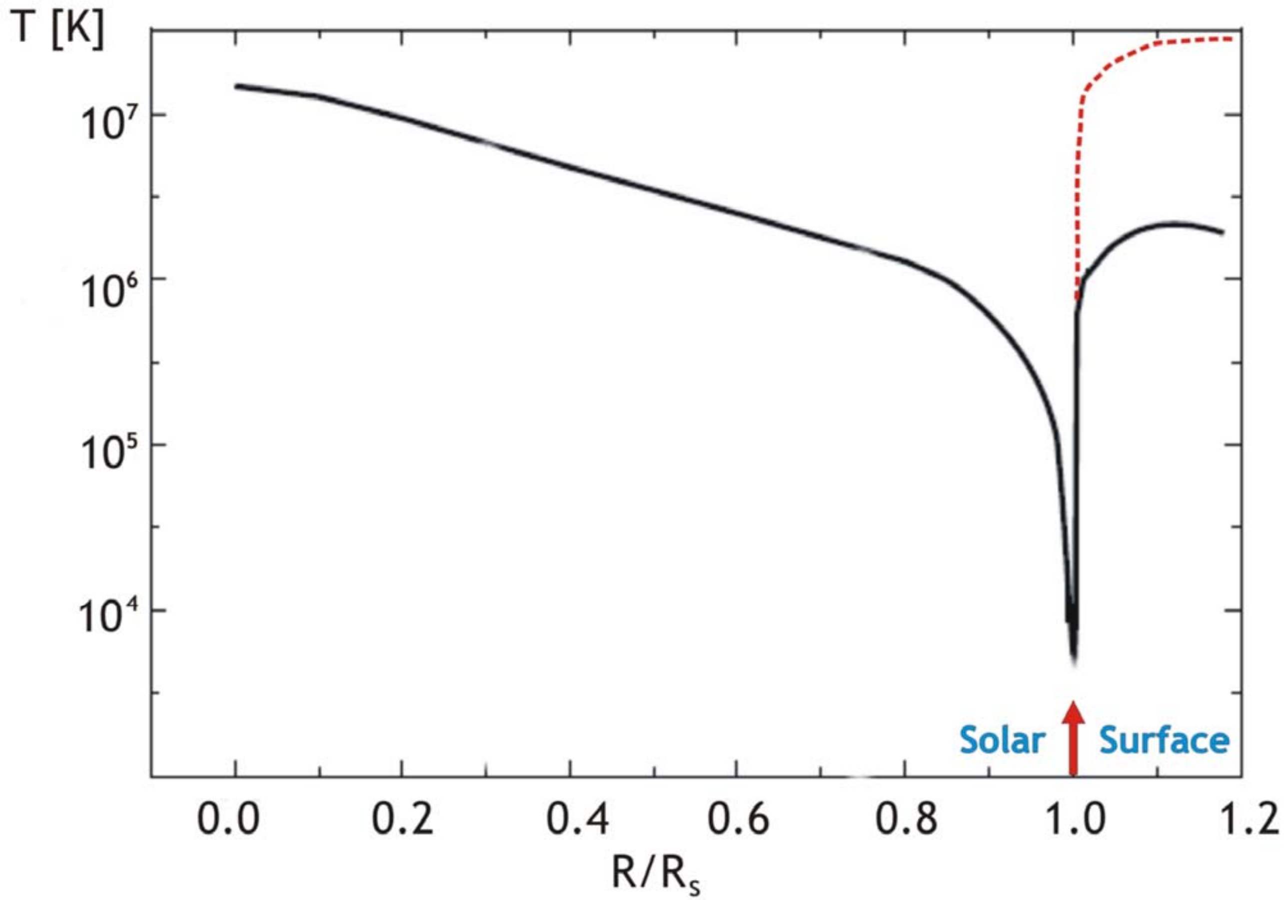
➔ The mechanism that heats the solar corona remains elusive.

➔ Everything above the photosphere … would not be there at all.

M.J. Aschwanden, A.I. Poland, D.M. Rabin, A.R.A.A. 39 (**2001**) 75

C.J. Schrijver, A.A. van Ballegooijen, ApJ. 630 (1st September **2005**) 552

Solar temperature distribution



↛ **2nd Law of Thermodynamics?** ➔ **solar corona problem**

Grotrian (1939)

➔ ***"The enigma of coronal heating represents one of the most challenging problems in astrophysics at the present time."***

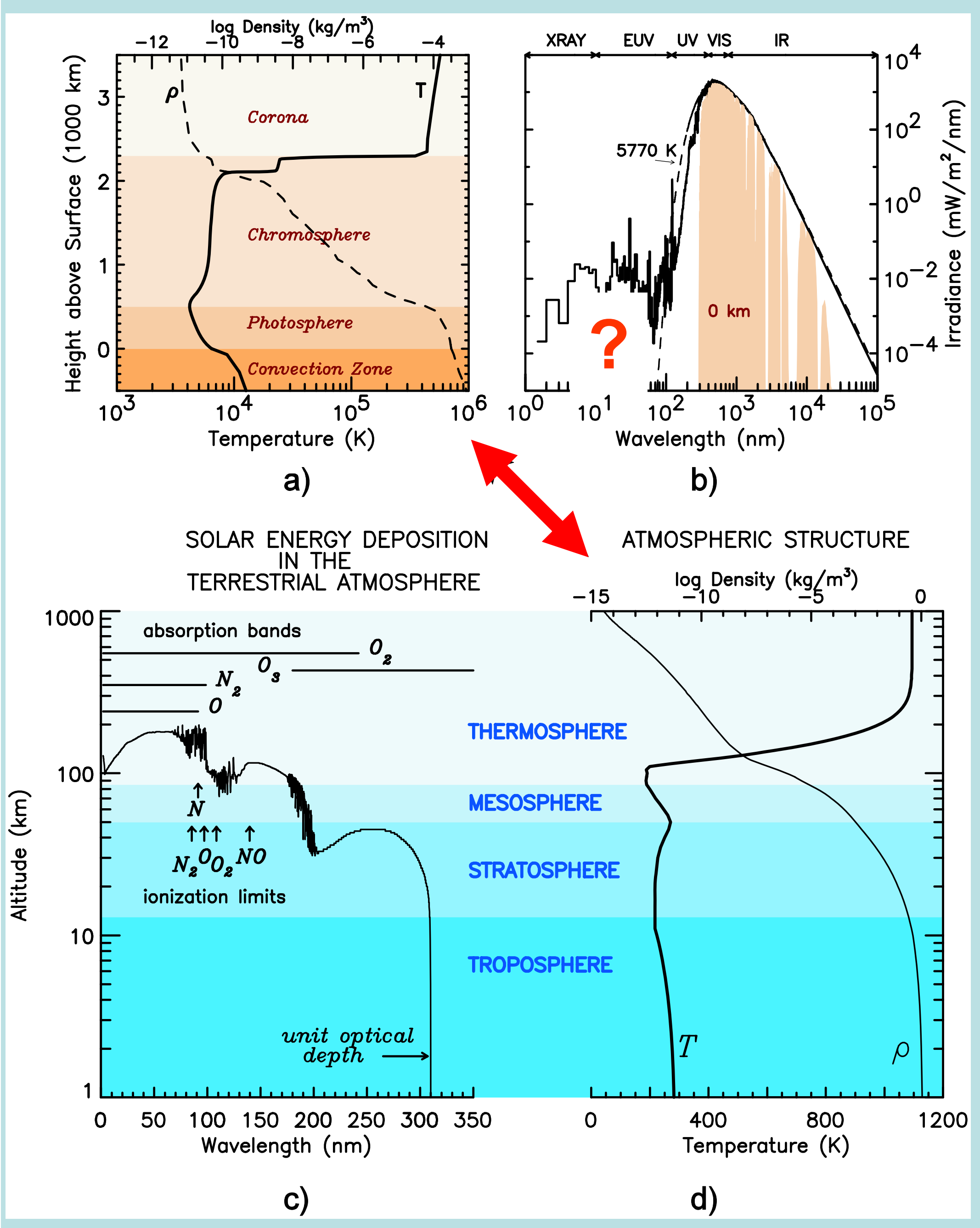
E. R. Priest, D. W. Longcope, J. Heyvaerts, ApJ. 624 **(2005)** 1057

→ 2nd Law of Thermodynamics →

Heat transfer → hotter-to-cooler

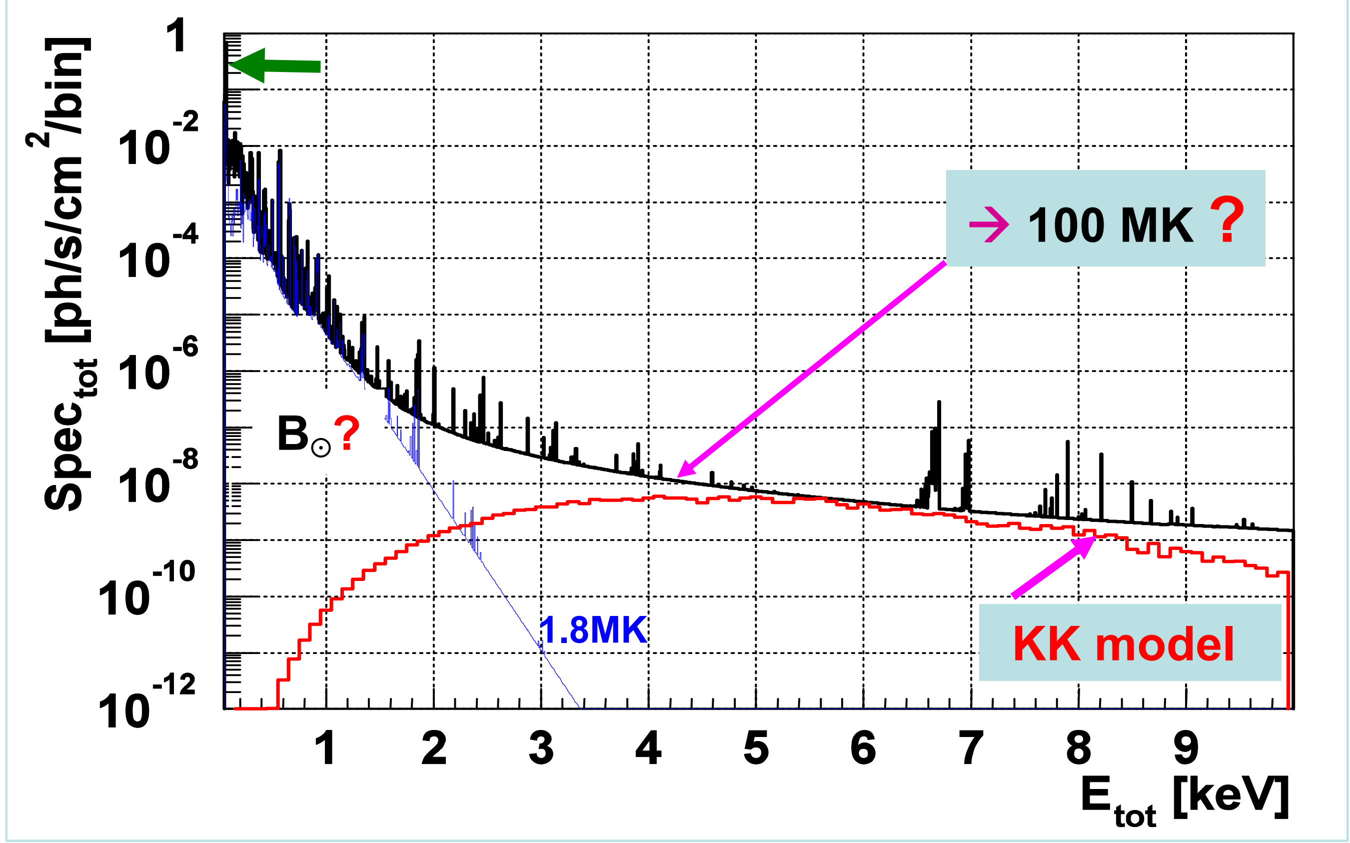
Suggestion:

→ solar X-ray self-irradiation



L. DiLella, K. Z. Astropart. Phys. 19 (2003) 145

Observational evidence for gravitationally trapped massive axion(-like) particles



KK-*axions*

↓

generic

↓

$g_{a\gamma\gamma} \sim 9 \cdot 10^{-14} GeV^{-1}$

$\overline{T}_{flare} < 20MK$

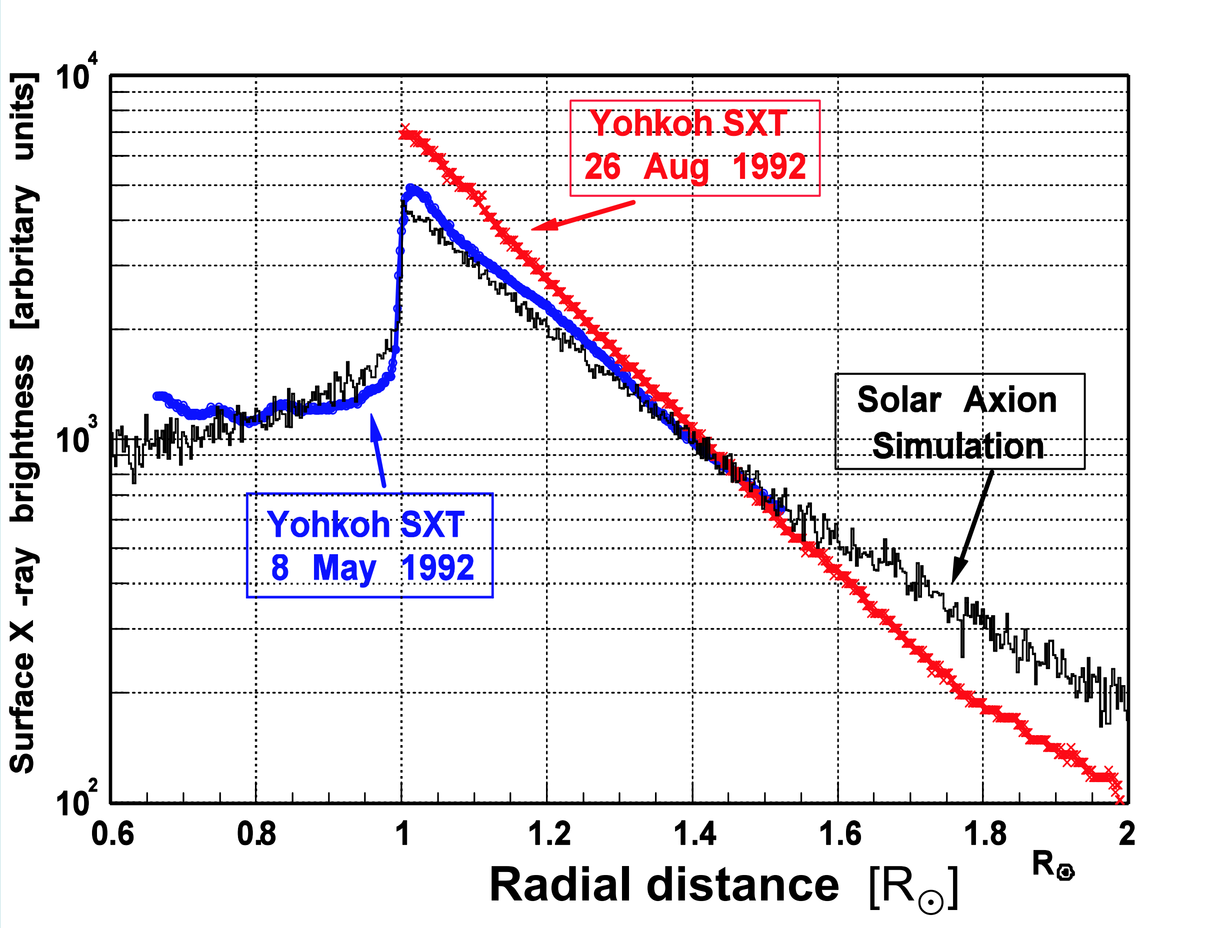
Reconstructed X-ray spectrum

➔ ***non-flaring Sun @ solar minimum*** [X].

[X] G. Peres, S. Orlando, F. Reale, R. Rosner, H. Hudson, ApJ. 528 (2000) 537

L. DiLella, K. Z., Astropart. Phys. 19 (**2003**) 145

Quiet Sun X-rays as Signature for New Particles



Soft X-ray surface brightness from the quiet Sun.

Simulation with trapped solar KK-axions ⇒ $g_{a\gamma\gamma}<40\cdot10^{-14}GeV^{-1}$.

26 August: **off-pointing**

(JL Culhane, Adv. Space Res. 19 (1997) 1839)

- **Diffuse emission.**
- **Hydrostatic equilibrium doesn't fit observations.**
- **closed loops of increasing height … cannot reproduce the observed behaviour of T & ρ @ diffuse structure.**
- **AR emission … no strong correlation with T_{plasma}** ➔ **This suggests that the nature of coronal heating mechanism does not change through the cycle.**

. . . .

- **Soft X-Ray Emission has been detected from a north polar coronal hole.**
  (see Foley, Culhane, Acton, ApJ. 491 (1997) 933)

Z., Dennerl, DiLella, Hoffmann, Jacoby, Papaevangelou, ApJ. 607 (**2004**) 575

These results favor a coronal heating mechanism that involves the deposition of non-thermal energy beyond the observed heights in the corona.

⇩

BUT ➔ *no evidence of non-thermal heating at these regions*

\+

the inner corona

http://hbar.stanford.edu/sturrock/wheatland/newsletter.html

RHESSI Major Events

****************************2005***************************

October 18, 09:00 UT RHESSI was again put into drift mode to view the x-ray emission of the quiet Sun "out of the corner of its eye". This mode began at the time noted above. RHESSI was commanded back to the Sun at 06:10 UT on **October 28**, and arrived shortly after 08:00 UT on that day. The Sun was very quiet during this time, but anyone wishing to analyze data within that interval should contact the instrument team. ➔ **10 days**

July 19, 06:00 UT At this time, RHESSI was put in a new mode that let it drift up to 1 degree away from the Sun and slewed back, repeatedly. ***The purpose of this mode was to study the x-ray emission of the quiet Sun*** (the Sun was extremely quiet beginning at this time). RHESSI returned to normal operations at around 04:00 UT on **July 26**. If you wish to analyze any flares during this week, please contact the instrument team. ➔ **7 days**

+ presentation next week.

mimic CAST ?

$\Downarrow$

indirect axion-signal ?

➔ **magnetic fields** of ***several* kG *in sunspots***

➔ probably **~10 T** in the tachocline (-200000 km)

➔ X-rays: $\gamma \rightleftarrows$ **axion**

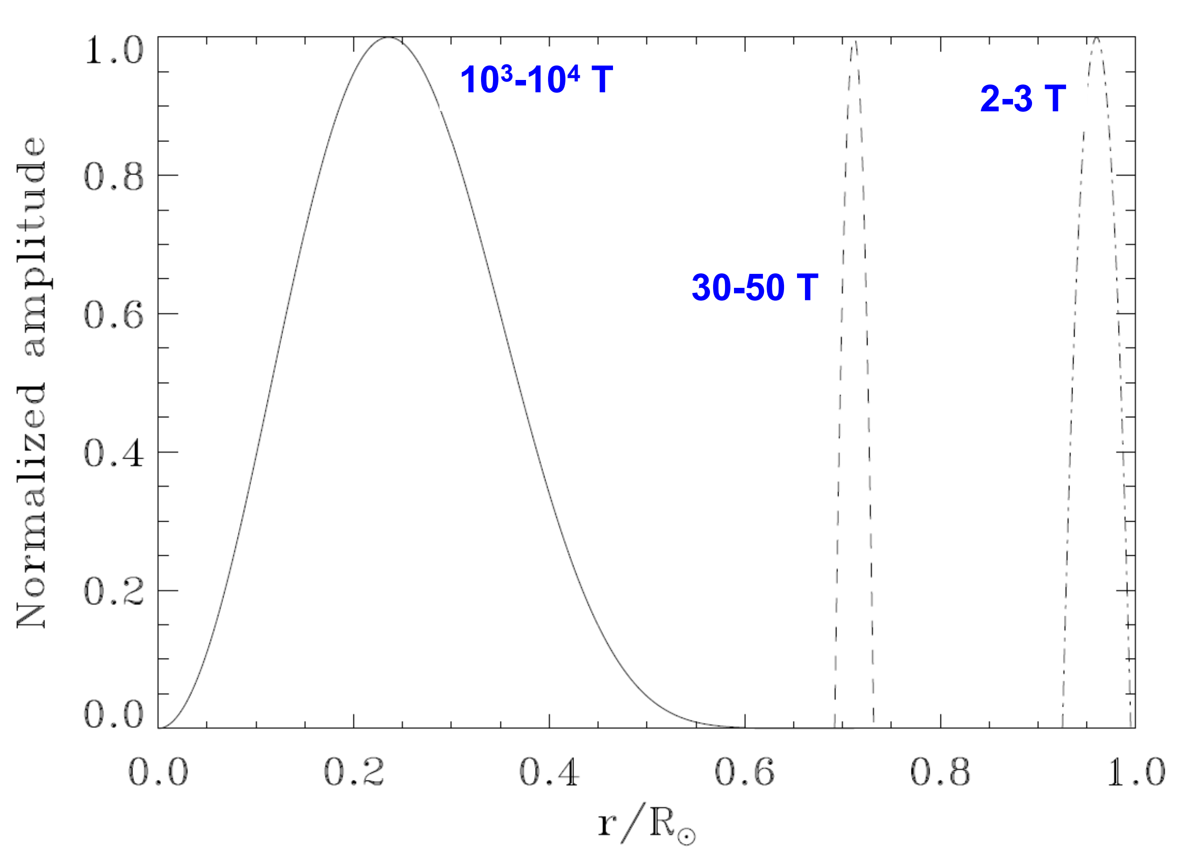
M. Aschwanden, *Physics of the Solar Corona* (**2004**) p.175

It is believed that much, if not all, of the magnetic flux penetrating the **photosphere** is aggregated in 200-300 km Ø, in which the field strength is of order **1.5 kGauss** (~2% of the surface).

➔ **Visible light:** $L_\odot \rightleftarrows L_{axion}$

P.A. Sturrock, ApJ. 521 (**1999**) 451
J. Sanchez Almeida A.& A. (**2005**) in press, astro-ph/0504339

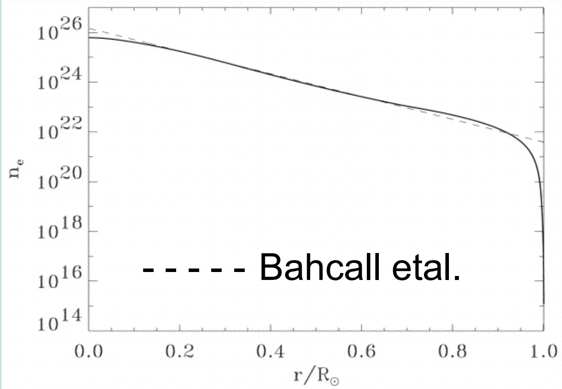
Solar seismic models + the ν-predictions



...seismic models are very close to the real Sun in the regions of concern.

But ➔

... as far as the internal rotation profile is not included in the study, new surprises may appear ...



Magnetic fields simulated. The amplitudes of the fields have been normalized by their maximum intensity.

S. Couvidat, S. Turck-Chieze, A. G. Kosovichev. ApJ. 599 (**2003**) 1434

CAST @ Sun ?

P. Sikivie [1983]

➔ 2nd (transient) component for solar X-ray emission

$$a + \gamma_B \rightarrow \gamma \quad \text{or} \quad \gamma + \gamma_B \rightarrow a$$

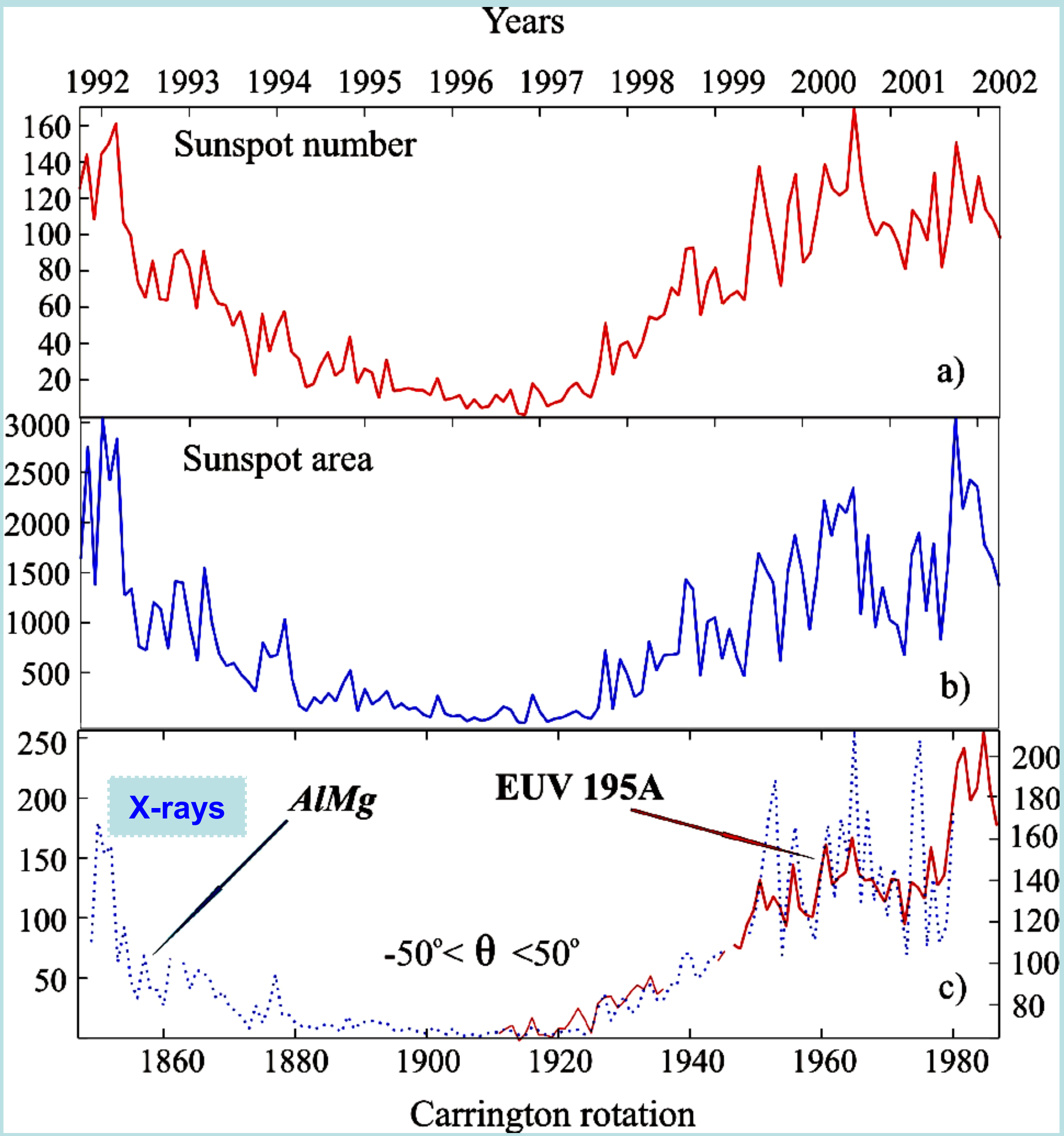
$$I_x \sim B^2$$

➔ *solar X-rays below ~1 keV?*

+

transient phenomena?

Sunspot numbers and coronal intensity



http://soi.stanford.edu/press/aas06-02/

➔ **The magnetic field plays a crucial role in heating the solar corona** (this has been known for many years) ➔ ***the exact energy release mechanism(s) is(are) still unknown*.**

➔ **the process by which it is converted into heat and other forms remains *a nagging unsolved problem*.**

K. Galsgaard, C.E. Parnell, A.& A. 439 (August **2005**) 335
R.B. Dahlburg, J.A. Klimchuk, S.K. Antiochos, ApJ. 622 (**2005**) 1191

➔ the **reconnection** of **B** lines plays a key role in .. ***solar flares***, ***CME***s ….

➔ (μ)flares ⊗ **polarity inversion** lines with strong sheared **B** lines.

➔ In ARs, …places with field as strong or stronger than in brightest features, but the corona is dimmer.
➔ ***...a hidden process*** **controls coronal heating.**

➔ Emerging Φ ⊗ trigger ***transient brightenings*** (~10^{24} – 10^{28} ergs).

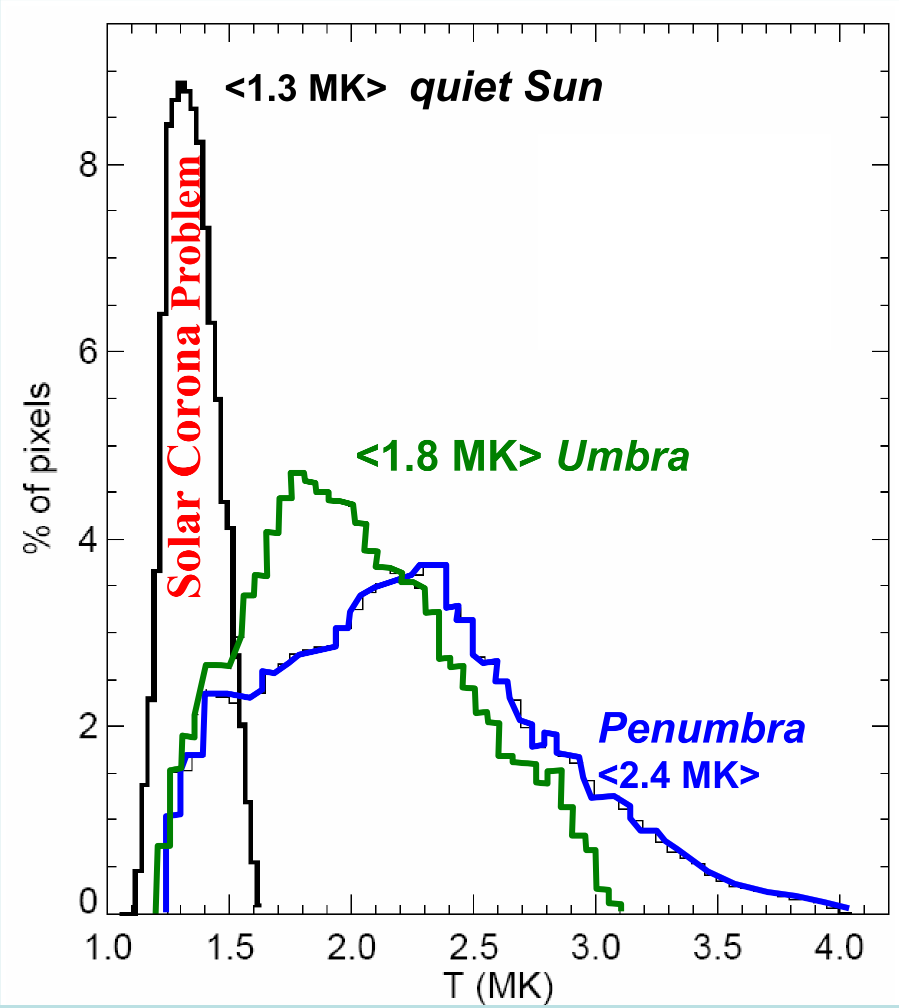
⇩

origin?

M. Hahn et al., ApJ 629 (**2005**) 1135; M. Barta, M. Karlicky, ApJ (**2005**) ***in press***
D.A. Falconer et al., ApJ 482 (**1997**) 519; 593 (**2003**) 549
T. Shimizu, IAU Symp. No. 223 (**2004**) 345

SUNSPOTS

➔ Yohkoh - XRTelescope



Temperature distributions

Sunspots = "*dark spots*" → T ⇩

➔ **photosphere**
~ 4500K ➔ ***heat flux problem***
in ***umbra + penumbra***
Spruit, Scharmer, A.&A. (2005), astro-ph/0508504

➔ **Corona**
Soft X-ray fluxes T ⇧

Sunspots:	~ 50 - 190 DN/s
Quiet Sun:	~ 10 - 50 DN/s
(**AR**s:	~ 500 - 4000 DN/s)

→ ***sunspot plasma parameters***
are higher than @ quiet-Sun

➔ **B ~ 2 kG above most sunspots !**

A.Nindos, M.R.Kundu, S.M.White, K.Shibasaki, N.Gopalswamy,
ApJ. SUPPL. 130 (2000) 485

➔ **"… sunspots remain mysterious".**

➔ **The penumbral mystery … the very reason for its existence unknown.**

http://www.solarphysics.kva.se/NatureNov2002/background.html

The time variability is found almost everywhere in ARs & X-ray bright points, while ***no significant variability is found in quiet regions.***

→ **Quiet areas ≈ constant emission rate ≈ 13 DN/s/16# 's ≈ $5 \cdot 10^{24}$ erg/s**

→ **the fluctuation is consistent with the 1σ level of the photon noise.**

→ **the quiet region corona shows almost no variability above ~20 s:**

→ **QR corona is more continuously/continually heated than AR corona**

↛ **any small-scale activity @ quiet Sun,**

→ **except for X-ray bright points & "overheated" corona above ARs.**

→ **The time variability requires sudden energy releases in the corona, whereas the persistent corona apparently requires a certain heat input for a long time.**

→ **TEMPERATURE** → **quiet Sun diffuse corona ≈ 1.6 – 2.7 MK → stable**
→ **above active regions ≈ 3 – 5 MK → variable**

→ <u>**X-ray images ⊗ photospheric magnetograms:**</u>

the large majority of persistent enhanced coronal features observed in ARs have strong magnetic shear along neutral lines at their feet.

T. Shimizu, S. Tsuneta, ApJ. 486 (**1997**) 1045

Yohkoh/BCS data analysis →

2 components for the coronal heating:

- a universal Temperature in the quiet Sun & in ARs
  → *basic corona heating* ~ 2.5 MK

- high Temperature above ARs
  → *higher solar activity* ~ 4 MK

T. Watanabe et al., Sol. Phys. 157 (**1995**) 169

2 *different* mechanisms are apparently involved in coronal heating ⊗ ARs:

→ **steady heating mechanism**
→ **3-5 MK**

→ **transient heating**
→ **due to magnetic reconnection**
→ **~10 MK**

T.Yoshida, S. Tsuneta, ApJ. 459 (**1996**) 342
A.C. Sterling, HS Hudson, T. Watanabe ApJ. 479 (**1997**) L149

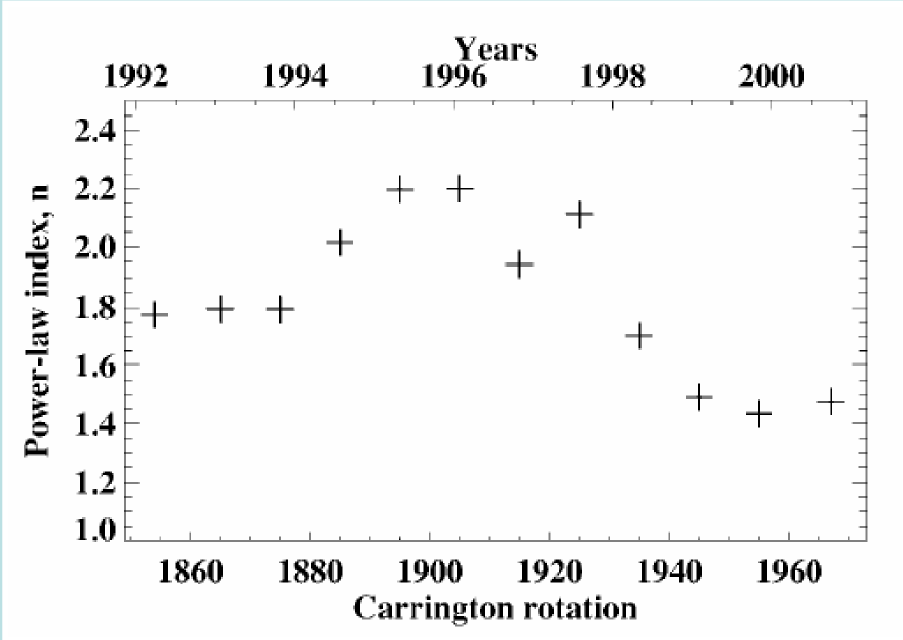
2 different components: → NOAA 7978 **Yohkoh**

→ **a steady heating mechanism (non-flaring)** **3-5 MK**

→ **an independent mechanism for heating flares** **>5 MK**

→ **both mechanisms energetically ~equal!**

T. Watanabe et al., Sol. Phys. 201 (**2001**) 1



Power-law index **n** of **$L_x \sim B^n$** $= f(\text{time})$ ➔ **YOHKOH** / XRT

The relation between the average solar soft X-ray intensity of the corona (<4.4keV) is ~B^2 with an averaged index close to 2.

Benevolenskaya, Kosovichev, Lemen, Scherrer, Slater ApJ. 571 (**2002**) L181

Note: **axion-to-photon oscillation** $\propto$ **$(BL)^2$** ➔ e.g., in **CAST**

D.H.H. Hoffmann, K. Z., N.P.B S (**2006**) *in press.*

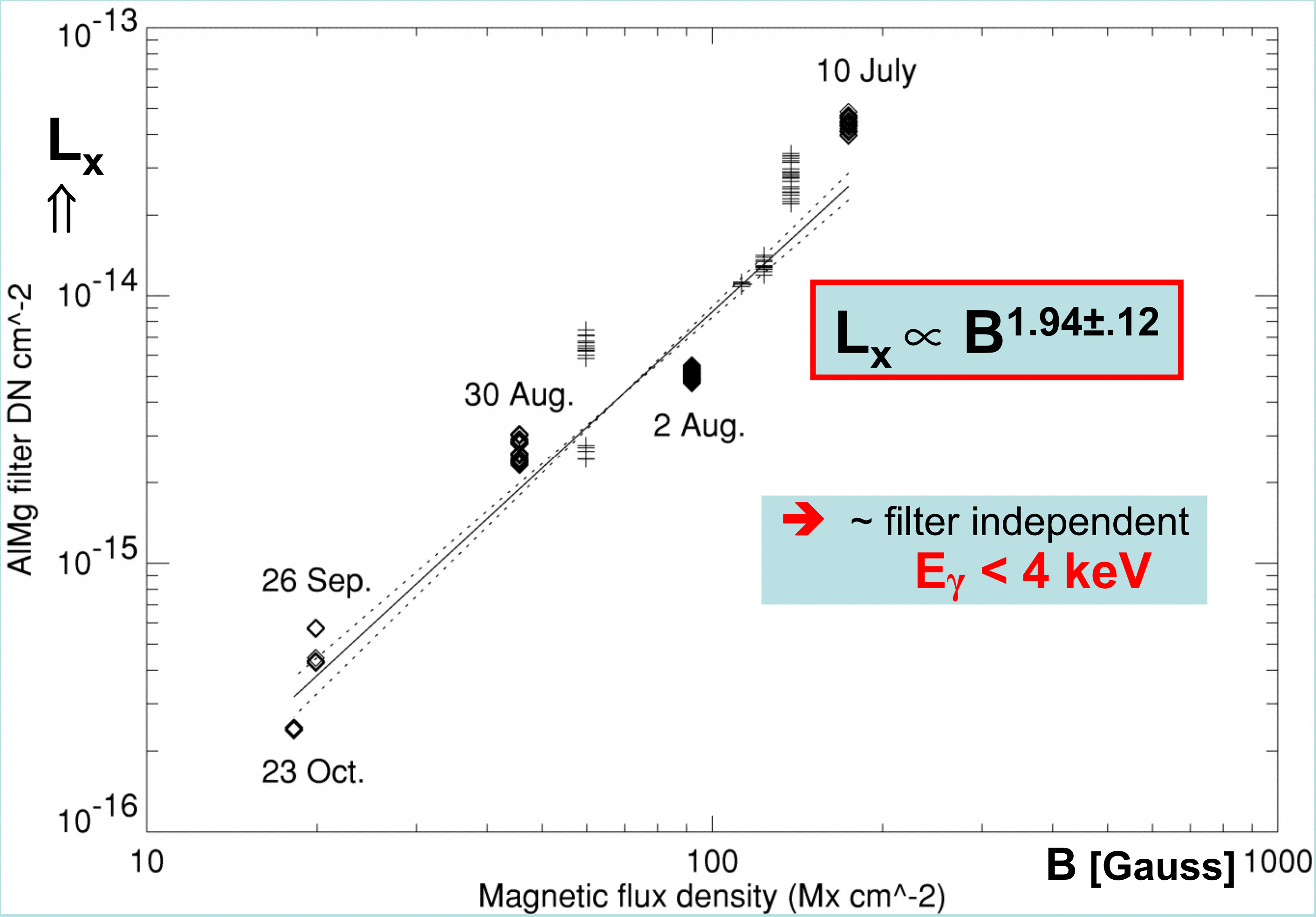
….. **essentially NO correlation between the X-ray flux & the average line-of-sight magnetic field <B>.**

R. Wolfson, C.B. Roald, P.A. Sturrock, ApJ. 539 (**2000**) 995

\+ **P.A. Sturrock**, *Private communication*

➔ it resembles **Primakoff effect.**

The long-term evolution of AR 7978 (S10°) ➔ Yohkoh / SXT



X-ray flux outside flaring times in AR7978

- ***increased steeply @ flux emergence***

\- - - - - + - - - - -

← ***decreased @ decay phase***

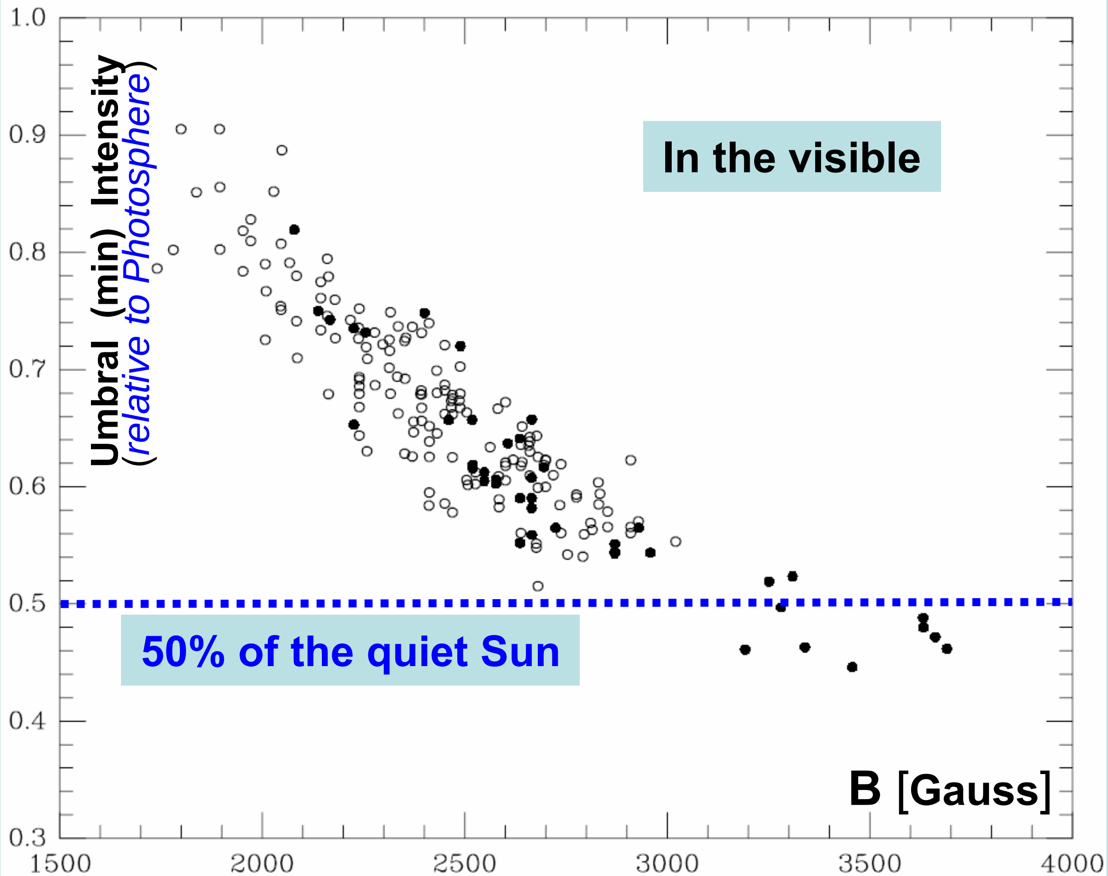
<X-ray flux> / (cm^2 -AR7978) vs. magnetic field <**B**>(=total magnetic flux / $\mathbf{AR}_{surface}$).
Solid line: the linear fit; dotted lines: the 3σ error in the slope of the solid curve.
Only the decaying phase (diamonds) is included in the fit → **July-Nov. 1996**

➔ The only sizable and long-lived AR on the solar disk @ 5 solar rotations

➔ it produced 3 slow CMEs + 3 major flares, **L. van Driel-Gesztelyi, et al., ApJ. 586 (2003) 579**

✚ RHESSI observations often show hard x-ray emission from non-flaring active regions.

American Geophysical Union, Fall Meeting 2005, abstract #SH11A-0242 (5-9/12/2005),
Hannah, Hurford, Hudson, Title: ***A Search for Hard X-Ray Emission from the Quiet Spotless Sun***



SUNSPOTS

Umbral normalized continuum intensity vs. umbral field strength **B**. Plotted is the minimum value and the maximum value of **B** of each sunspot.

Filled circles (1990–1991)

Open circles (2000–2001)

A number of fundamental questions remain unanswered.

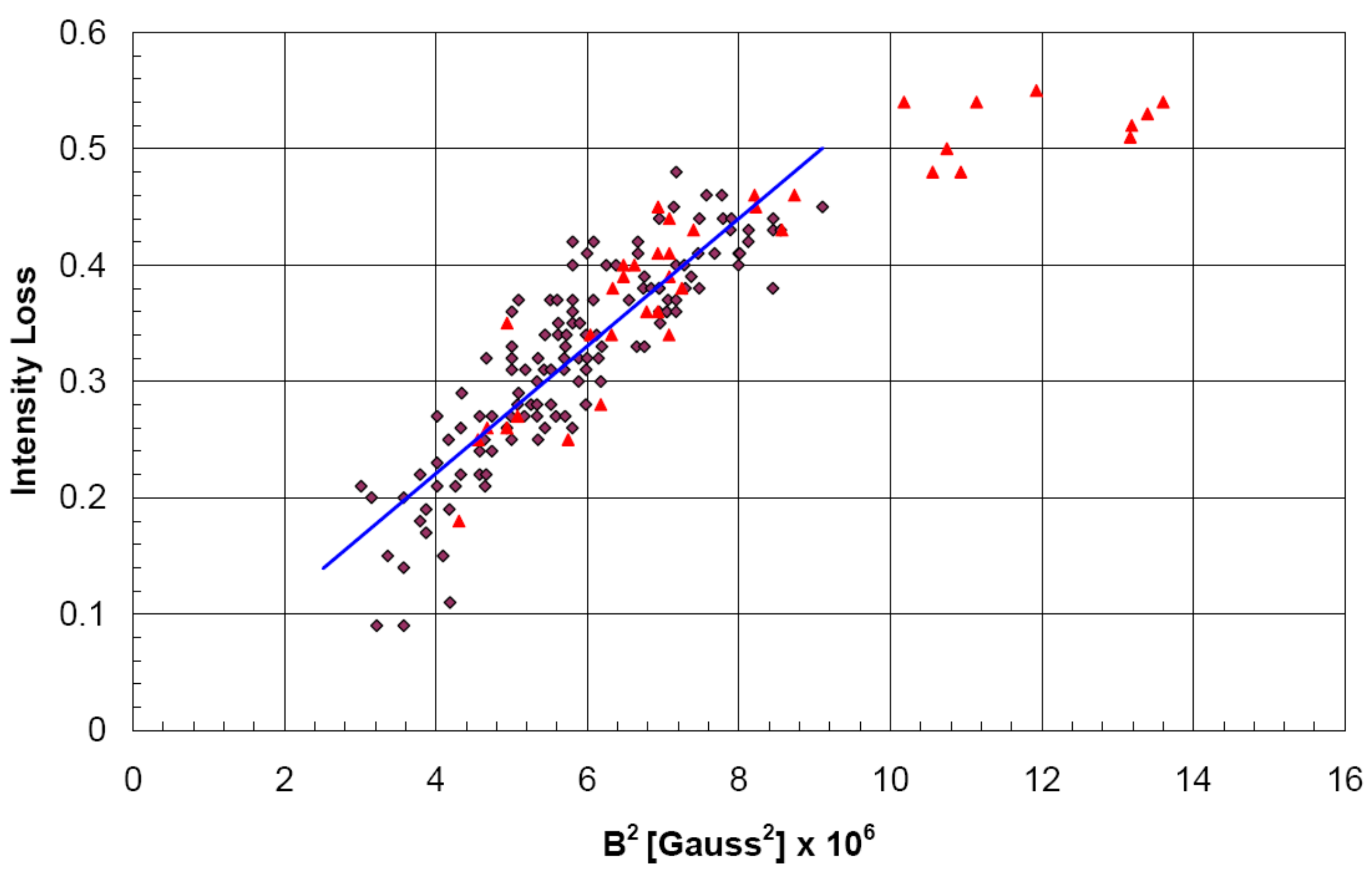
➔ ***What determines the intrinsic brightness of umbrae and penumbrae, in spite of the strong magnetic field which inhibits convection?***

➔ ***Is an additional mechanism needed?***

➔ ***How is the umbral chromosphere heated?***

➔ ***Why are penumbrae brighter? ….***

S.K. Solanki, A.&A. Rev. 11 (**2003**) 153



Thanks Thomas Papaevangelou

S.K. Solanki, A.&A. Rev. 11 (**2003**) 153

FLARES

→ **The precise causes of solar flares & CMEs is one of the great solar mysteries** → **2003**

→ ⊗ **B**

→ what initiates the energy release?

→ what makes some magnetic configurations more likely to flare than others?

→ Fundamental question:

how and why ***reconnection*** starts as an explosive process in flares?

→ ***The trigger site of flares is still elusive.***

→ ***Understanding how energy is released in solar flares is a central question in astrophysics*** → **1999**

G. Barnes, D. W. Longcope, K. D. Leka, ApJ. 629 (**2005**) 561

K. Kusano, T. Maeshiro, T. Yokoyama, T. Sakurai, ApJ. 610 (**2004**) 537

G. Allen Gary, L.R. Moore, ApJ. 611 (**2004**) 545

DH Hathaway, http://science.msfc.nasa.gov/ssl/pad/solar/quests.html (**2003**)

Warren, Bookbinder, Forbes, Golub, Hudson, Reeves, Warshall ApJ. 527 (20.12.1999) L121

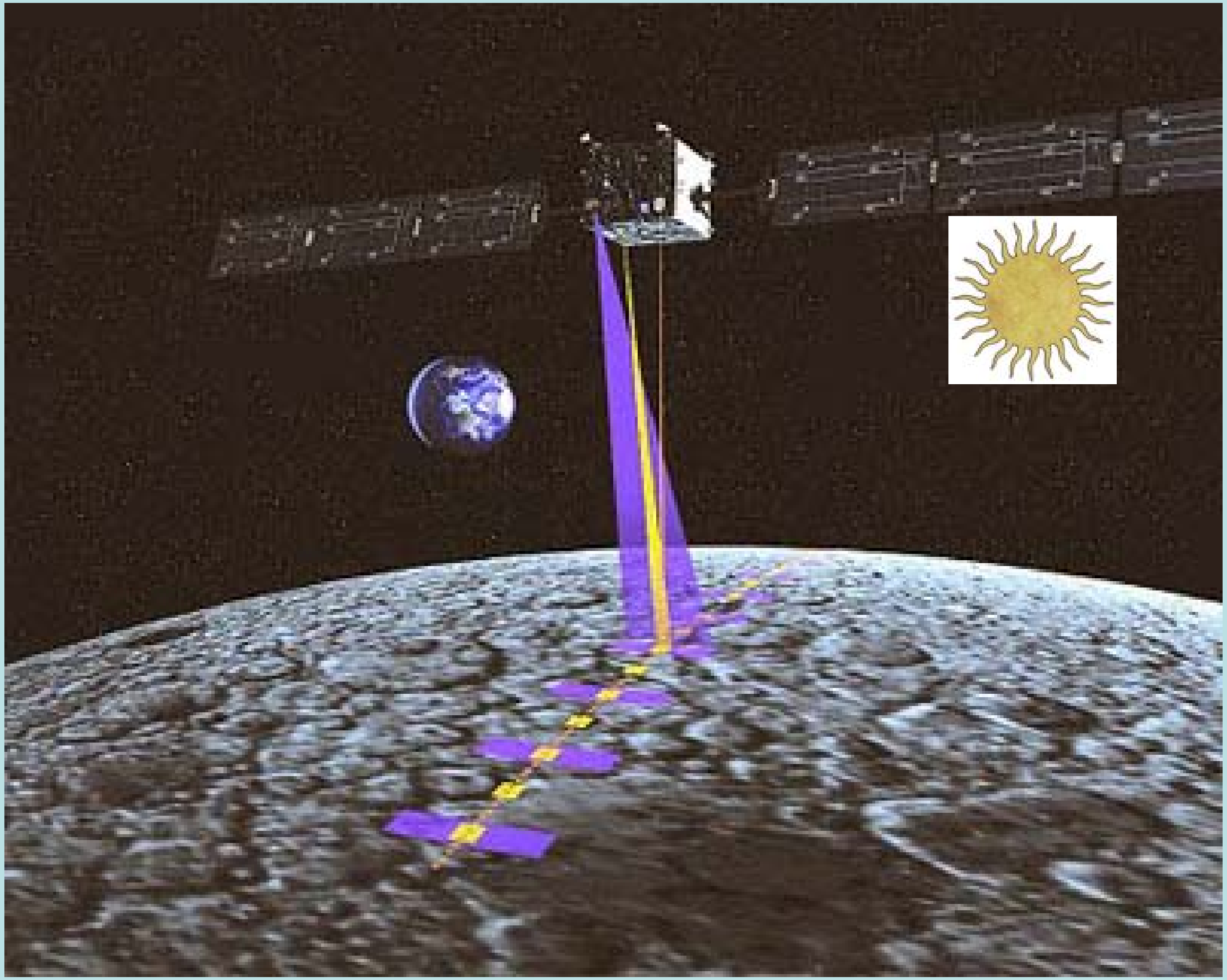
→ **Less magnetic activity = fewer solar X-rays.**

→ The magnetic activity is determined by a magnetic dynamo within the Sun.

http://star-www.st-andrews.ac.uk/~mrt2/XRU2a.pdf

SMART: ***orbiting X-ray detectors*** → ***dark*** **moon** → **large volume + backgr.**

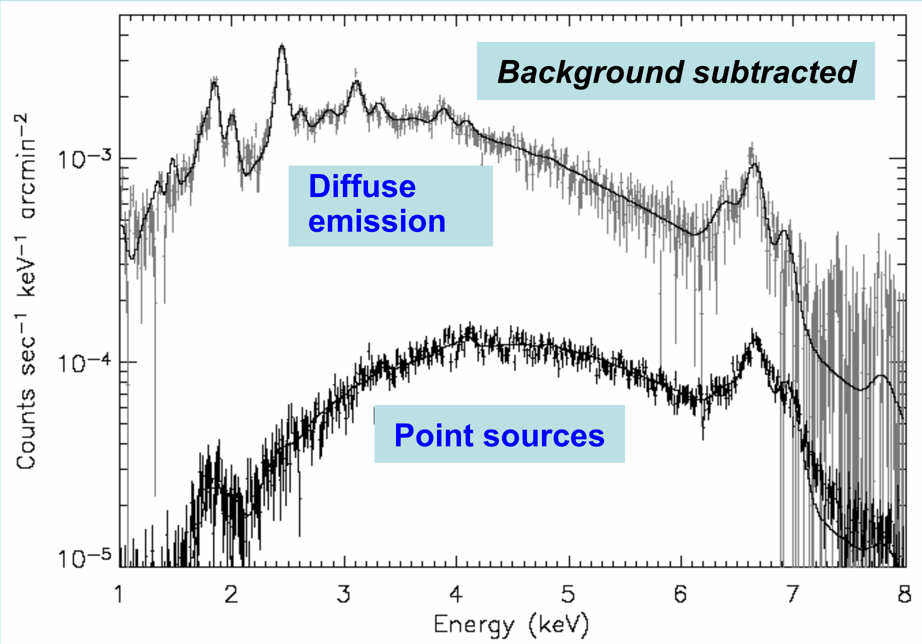
→ **Sun**

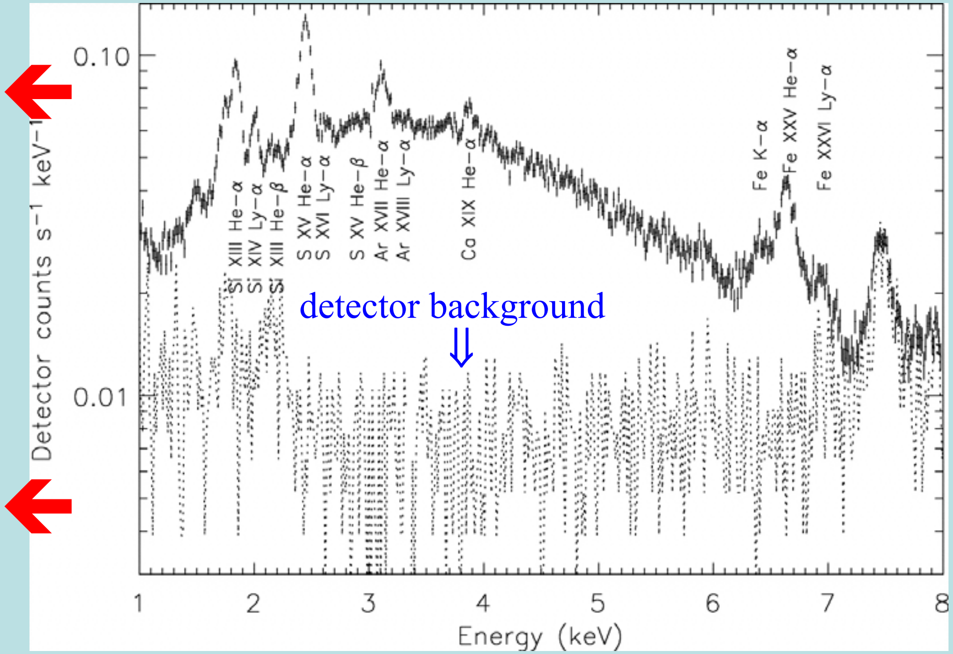


collaboration with
Observatory Helsinki

Search for ***massive ~axions*** → spontaneous radiative decays **a** $\rightarrow \gamma\gamma$

DIFFUSE X-RAY EMISSION OF THE GALACTIC CENTER → Chandra



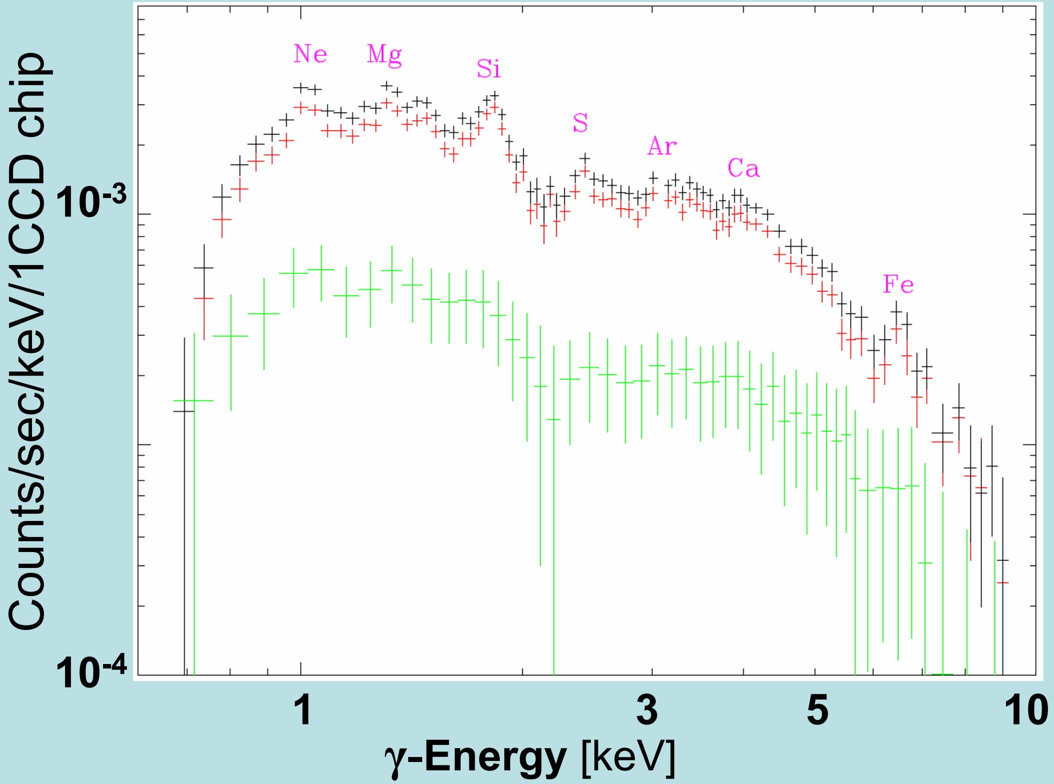


…this soft plasma is probably heated by supernovae, along with a small contribution from the winds of massive Wolf-Rayet and O stars. The kT~8 keV component is more spatially uniform… Neither supernova remnants nor WR/O stars are observed to produce thermal plasma hotter than ~3 keV. Moreover, ***a kT ~ 8 keV plasma would be too hot to be bound to the Galactic center***, and therefore would form a slow wind or fountain of plasma.

Alternative explanations for the hard diffuse emission that were intended to lessen the energy required are equally unsatisfying. The suggestion that the hard diffuse emission originates from undetected stellar X-ray sources is unlikely because ***there is no known class of source that is numerous enough, bright enough, and hot enough to produce the observed flux of kT≈ 8 keV diffuse emission.*** We are left to conclude that either there is a significant shortcoming in our understanding of the mechanisms that heat the interstellar medium, or that a population of faint (< 10^{31} erg s^{-1}), hard X-ray sources that are a factor of 10 more numerous than CVs remains to be discovered. M. Muno et al., ApJ. 613 (**2004**) 326

→**Chandra** ***confirmed the astonishing evidence of a diffuse, hot, plasma at*** **T~90 MK** ***to extend over*** **a few 100 pc** ***in GC*** **(→ ~ 9MK).** R. Belmont et al., ApJL. (20.9.**2005**)

Galactic Plane Diffuse & Point Source Spectra ➔ CHANDRA



spectral similarity between diffuse Galactic Plane and G.C. ➔ **they have similar origin?**

INTEGRAL: hard x-rays seem to be smoothly connected to γ's ➔ **suspect:** a common physical mechanism in the G.C. & G.Pl. behind the non-thermal diffuse emission of photons from few keV to ~MeV**!**

Energy spectra: total X-rays (***black***), sum of all point sources (***green***), their difference, i.e. the Galactic Plane diffuse emission (***red***) ➔ makes ~90% of the X-ray emission.

➔ **Questions:** how to produce & maintain a ~5-10keV H.E.plasma**?** how can it be bound by Galactic gravity**?** Energy density ~10 eV/cm^3 is 10-100x of the interstellar space like **CR**s, **B**$_{\text{galactic}}$ or **ISM**edium ➔ ***currently no accepted theoretical models can explain the long standing mystery of GRXEmission.*** Fe-line significantly lower than expected from thermally equilibrium plasma ➔ ***non-thermal plasma*!**

➔Even hypothesizing a new population of much dimmer & numerous Galactic point sources, the observed X-ray flux cannot be explained ➔ X-ray emission from the G.Pl. has truly diffuse origin**!** in agreement with XMM survey with larger sky coverage. *K. Ebisawa et al., ApJ.* (**2005**), *astro-ph/0507185*

Massive clusters:

Self similar models (gravity & shock heating of the gas) predict Bremsstrahlung emission :

$$L_x \propto T_x^{2} \propto \rho^2 T^{1/2} R^3$$

The observed relation is much steeper :

$$L_x \propto T_x^{3.0}$$

➔ **ICM** is in smaller & cooler structures progressively underluminous ➔ ***underdense*** relative to grav. values

➔ poor clusters & groups: the ratio m_{ICM}-to-m_{DM} << the cosmic baryonic fraction approached in rich clusters.

➔ ***break of self-similarity*** suggestive for energy injection from non-gravitational processes.

➔ ***"additional" gas physics?***

➔ The source(s) of the **"excess" entropy** is still not known.

➔ **S-Z** effect is extremely sensitive to the presence of an entropy floor of the ICM → $y \propto \rho T R$

➔ analysis indicates that the entropy of the ICM has been significantly raised by some ***non-gravitational process(es).*** This corresponds to a thermal energy of 1-3 keV per particle for massive clusters.

➔ SNe explosions cannot be the sole contributor to the entropy floor: their impact ≤0.3 keV /particle.

➔ "X-ray Observations Deepen **Mystery** of *What Happens in the Cores of Galaxy Clusters*". Huge amounts of gas in cluster cores should cool and collapse @ 100-1000 M_o / year. Cold material and enhanced star formation is by an order of magnitude too low, i.e., large amounts of gas are not cooling completely.

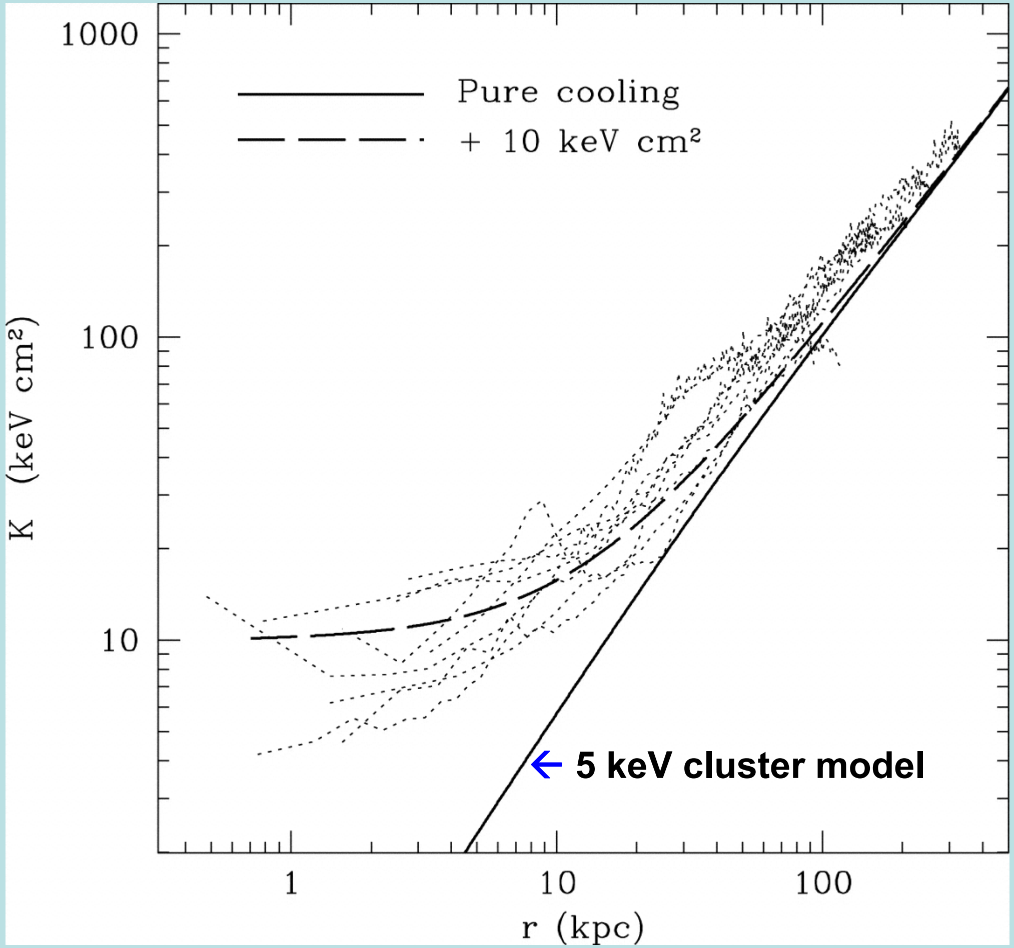
… ***some heating mechanism*** must prevent the ICM from radiative cooling.

➔ **a universal feedback mechanism ?**

➔ details of the heating process remain somewhat mysterious. ***Why does the gas cool down by 2/3 but not further?*** ➔ ***some thing is heating the gas again!***

C. Day, Phys. Today (**2003**) 16, S. Peng Oh, MNRAS 353 (**2004**) 468; Ikebe, Böhringer, Kitayama, ApJ. 611 (**2004**) 175, S. Nadis, Astronomy 33 (**2005**) 34, R. Demarco, P. Rosati, H.C. Ford, Modern Phys. Lett. A20 (**2005**) 1409, A. Cavalieri, A. Lapi, Y. Rephaeli ApJ. (**2005**) in press (astro-ph/0508287).

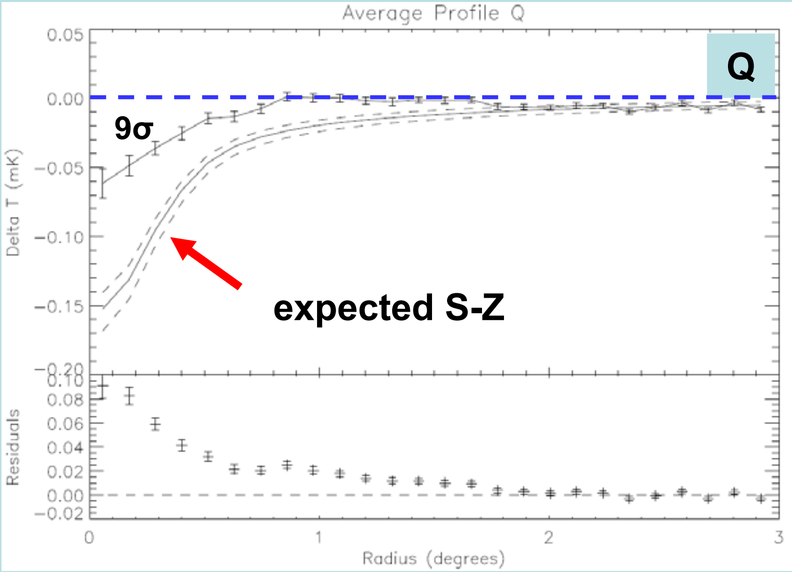
..halting cooling in clusters of Galaxies ➔ a ~30 years-long-standing puzzle

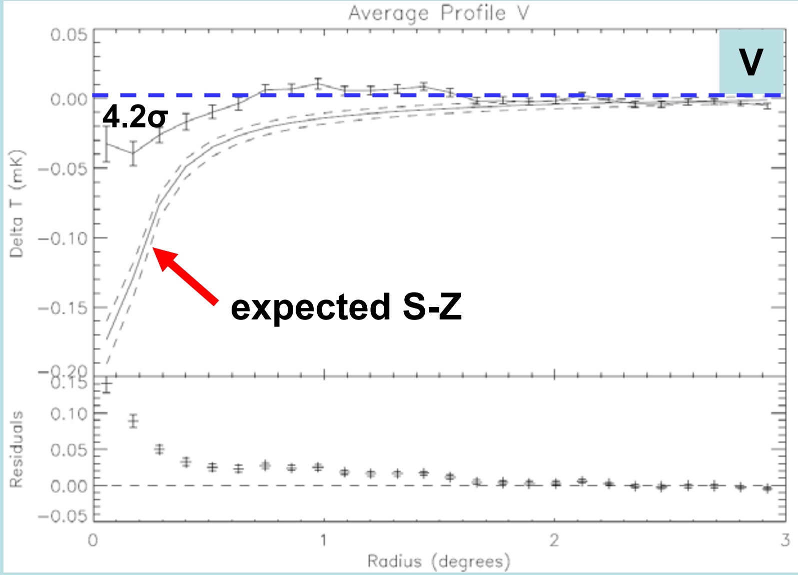


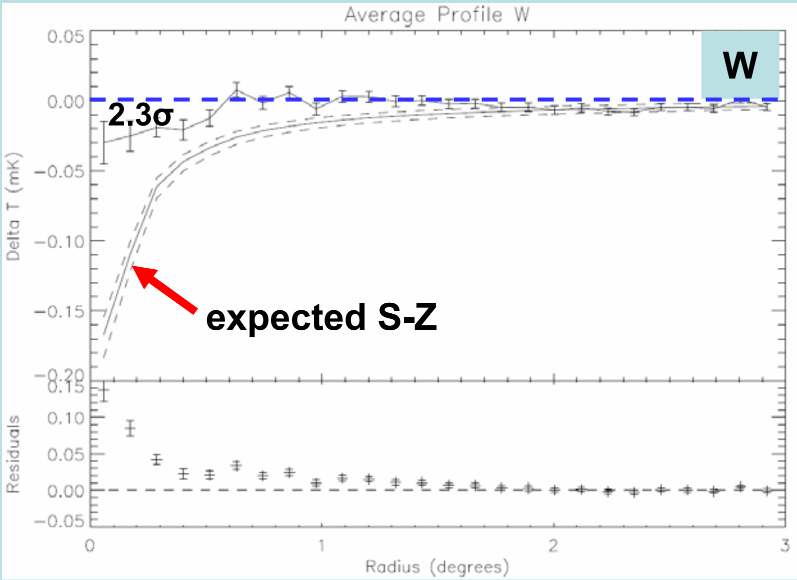
Early estimates of their mass accretion rates ranged as high as 10^2-10^3 $M_{\odot}$/yr. The problem with this interpretation of the data was that ***the mass sink for all this supposedly cooling and condensing gas has never been found.***

There is little evidence for emission lines from gas cooling much below about half the ambient temperature of the hot gas filling the cluster. **The cooling process seems to have stopped in its tracks, implying that *a compensating heat source resupplies the energy* radiated by the gas in cluster cores.**

Core entropy profiles of 9 classic cooling flow clusters. The dotted lines show the gas entropy ($K = kTn_e^{-2/3}$) profiles derived from the azimuthally averaged and deprojected density and temperature profiles. The profiles look strikingly similar considering that the cluster temperatures in this sample range from **2.2 to 7.4 keV**. Similarity in the entropy levels of the outer regions is consistent with the $T^{2/3}$ scaling. At larger radii the profiles seem to asymptotically approach the solid line showing the expected entropy profile for a **5 keV** cluster model, in which radiative cooling acts without triggering feedback. Simply adding a constant 10 keV cm² to the asymptotic model gives the thick dashed line, which is a good representation of the observed profiles within about 50 kpc (assuming H_0 = 70 km / s / Mpc). G.M. Voit, M. Donahue ApJ. 634 (**1.12.2005**) 955







X-rays observ. → Hot gas properties

31 co-added **WMAP** cluster fields →

expected S-Z effect 4x bigger → **less e^-**

→ Radiative decay of massive particles,

→ e.g. axions of the KK-type

→ to reconcile contradiction

R. Lieu, J.P.D. Mittaz, M. Bonamente, S-N.Zhang, astro-ph/**2005**10160

The average **WMAP** observed and predicted radial profile for the 31 clusters. The continuum of the prediction curve is fixed by alignment with the 2^{o}-3^{o} data, which is at a level higher than that of the central 1^{o} data points by 9σ (Q), 4.2σ (V), and 2.3σ (W).

Summary:

1) Radiative decay of trapped massive axion(-like) particles

→ Constant component of L_x

2) Oscillations between light ~axions & γ's inside $B_{solar\text{-}surface}$

→ Solar local effects in the eV-to-keV range

→ ⊗ 11-years solar cycle?

→ Suggestive for solar ~axion searches below ~1keV → 1eV

→ NO estimate of the solar axion spectrum below ~0.5 keV

3) $L^{2\text{-}8keV} \approx 10^{22\pm1}$ erg/s $\Rightarrow$ $10^{-12} L_\odot$

→ $P_{a\rightarrow\gamma}$ $(100km/2kG/10^{-10}GeV^{-1})$ + $\omega_{pl} \approx m_a$ **or** **PVLAS**

TSI → deficit @ sunspots

- Low energy solar axion Luminosity
- Intensity up to $\sim 1‰ L_\odot$?! ← **PVLAS**

4) Beyond the Sun → real plasma modified

→ Galactic Center, Galaxy Clusters + S-Z effect, ..., CXRB?

Thus, …

… important signals were overlooked ….

Otherwise → **F. Zwicky** →

Morphological Astronomy,
Berlin (**1957**) 132

“... *it is not clear how these startling results must ultimately be interpreted*.”

Basic idea: **Photons** ⇄ **axions** → ***γ-deficit*** ← ***γ-excess***

➔ **Solar X-ray spectrum** (quiet / active Sun) increasing @ low energies**!**

↛ ***solar axion spectrum* ≈ *hard X-ray component***

➔ ***Soft X-rays dominate solar L_x***

➔ **NO estimate of the solar axion spectrum below ~0.5 keV**

➔ (Primakoff)$_{\mathbf{B}\text{-}solar}$

Inside Sun ➔ >> axions @ lower energies (?)

Surface B⊙ ➔ axion-to-photon conversion
→ γ-***excess*** (e.g. sunspots, ARs, flares)
→ fits solar X-ray spectrum

➔ photon-to-axion conversion
→ visible γ's-to-axions
→ γ-***deficit*** @ visible (e.g. sunspots)

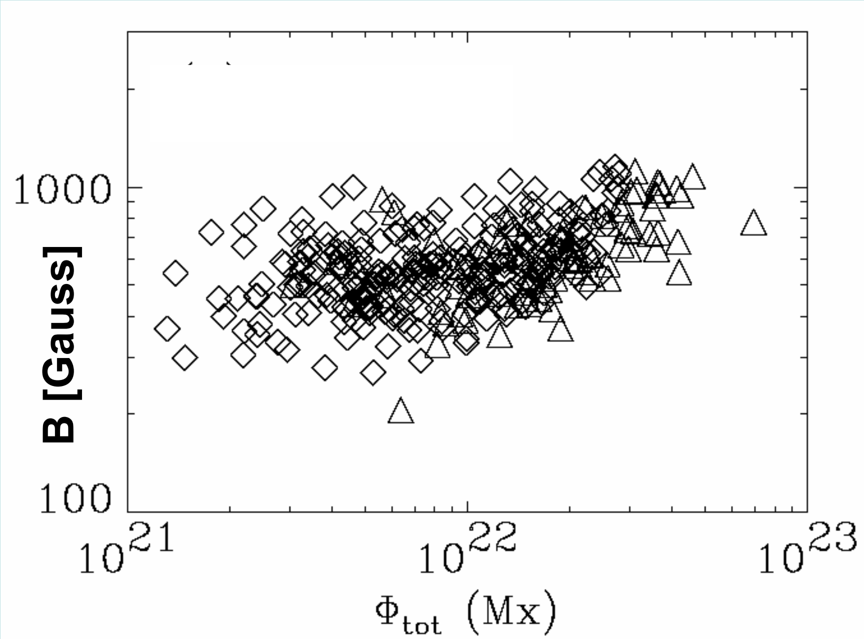
Further:

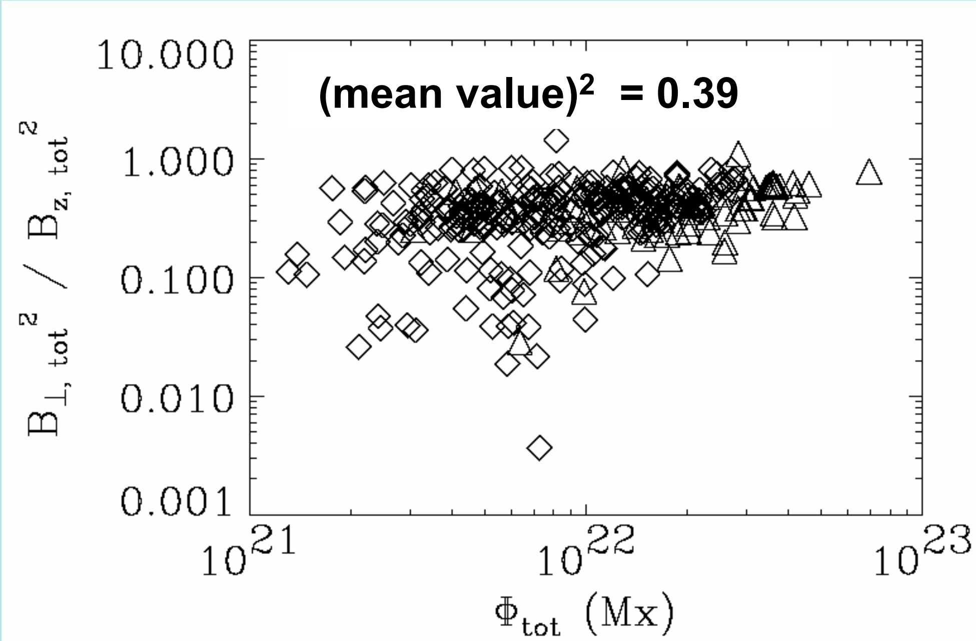
$L^{2\text{-}8keV} \approx 10^{22\pm1}$ erg/s ⇒ $10^{-12} L_\odot$ ➔ $P_{a\to\gamma}(100\mathrm{km}/2\mathrm{kG}/10^{-10}\mathrm{GeV}^{-1})$ + $\omega_{pl} \approx m_a$ **or** **PVLAS**

TSI → deficit @ sunspots ≈ ~5% to max. ~50% as expected for γ-to-axion oscillation(?)

➔ **1)** Low energy solar axion Luminosity, and **2)** intensity up to **~1‰$L_\odot$** **?!** ⇐ **PVLAS**

Scatter plots of magnetic variables in ARs.





Regions of strong magnetic field, such as sunspot umbrae, are typically darker in X-rays than regions of intermediate field strength such as plage.

A comparison of X-ray images of the Sun and full disk magnetograms shows a correlation between the locations of the brightest X-ray emission and the locations of bipolar magnetic active regions.

G.H. Fisher, D.W. Longcope, T.R. Metcalf, A.A. Pevtsov, ApJ. 508 (**1998**) 885

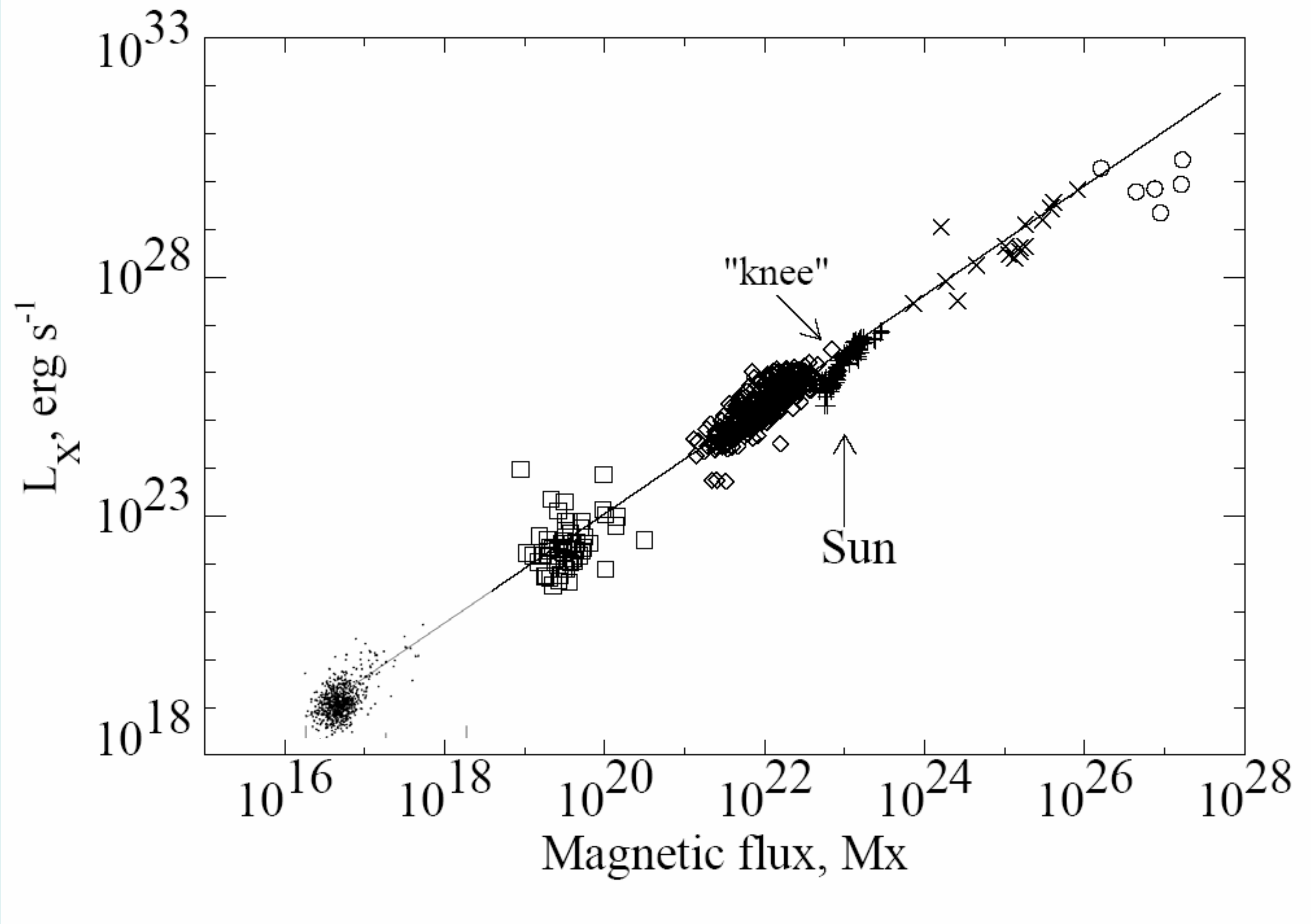
CIXS SMART 1

Collimator configuration	4^0 x 4^0, 20cm^2			6^0 x 6^0, 20cm^2			15^0 x 15^0, 20cm^2			6^0 x 6^0, 2cm^2 (Strawman-like)		
	S/N 100 days	time for whole object days	Pixel side km	S/N 100 days	time for whole object days	Pixel side km	S/N 100 days	time for whole object days	Pixel side km	S/N 100 days	time for whole object days	Pixel side km
Moon @100 km	1.9	40	7	4.2	27	10.5	27	10.5	26.8	.85	27	10.5
Moon @1000 km	19	7.4	70	42	4.9	105	270	1.9	268	8.5	4.9	105
Asteroid@25 km	163	2.1	1.75	367	1.4	2.6	2340	0.6	6.7	73	1.4	2.6
Asteroid@Flyby	1			1.6			4			0.3		

This ⇑ configuration corresponds to ~100m^3

http://shaper.bnsc.rl.ac.uk:8080/SMART-1/CIXS_PART_1.doc

THE RELATIONSHIP BETWEEN X-RAY RADIANCE & MAGNETIC FLUX



➔ $L_x \otimes B$

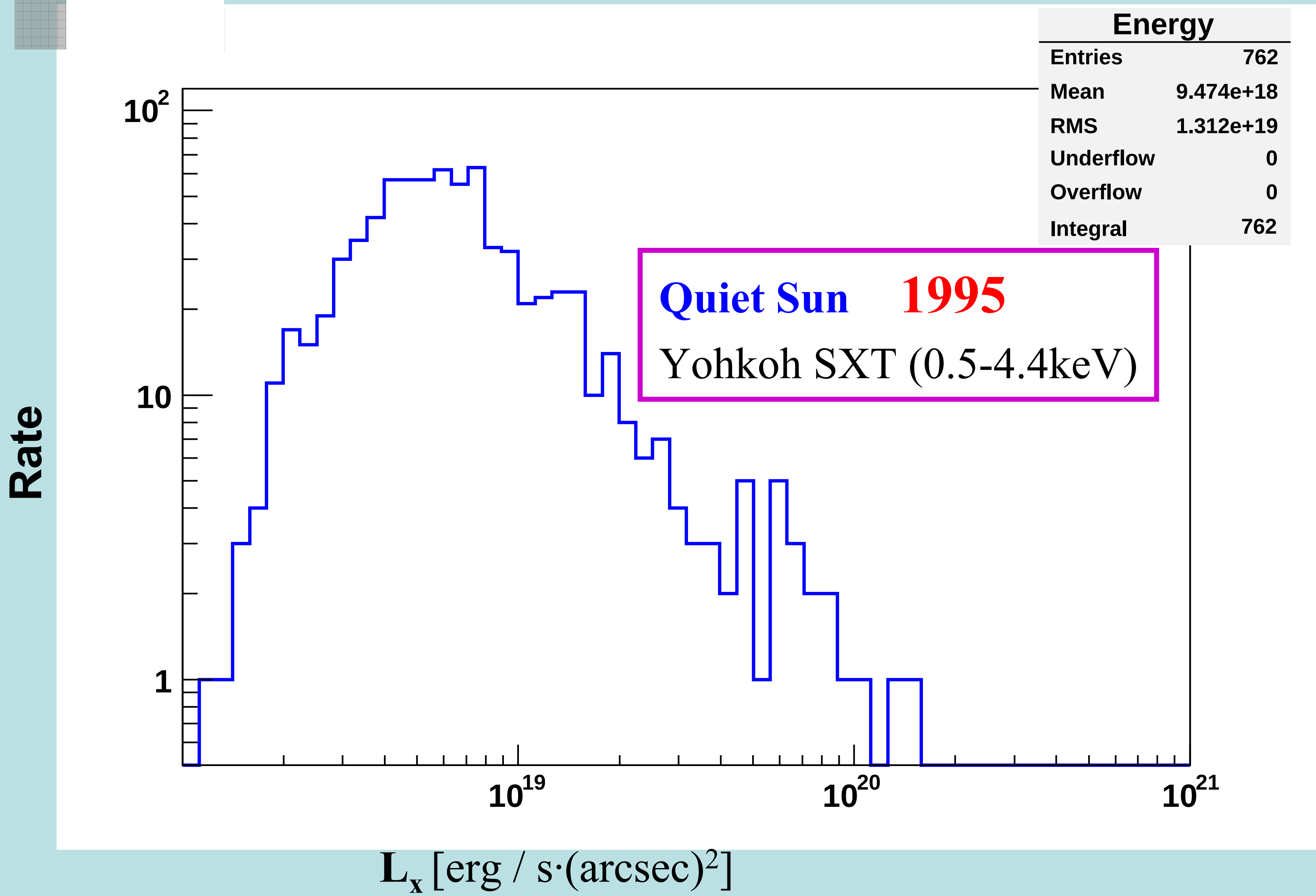
X-ray spectral radiance L_X vs. total unsigned magnetic flux for solar and stellar objects.

Dots: Quiet Sun. **Squares**: X-ray bright points. **Diamonds**: Solar active regions.

Pluses: Solar disk averages. **Crosses**: G, K, and M dwarfs. **Circles**: T Tauri stars.

Solid line: Power-law approximation $L_X \sim \Phi^{1.15}$ of combined data set.

A.A. Pevtsov et al., ApJ. 598 (1.12.**2003**) 1387



➔ To get a corresponding total X-ray luminosity ➔ x2.5·10^6

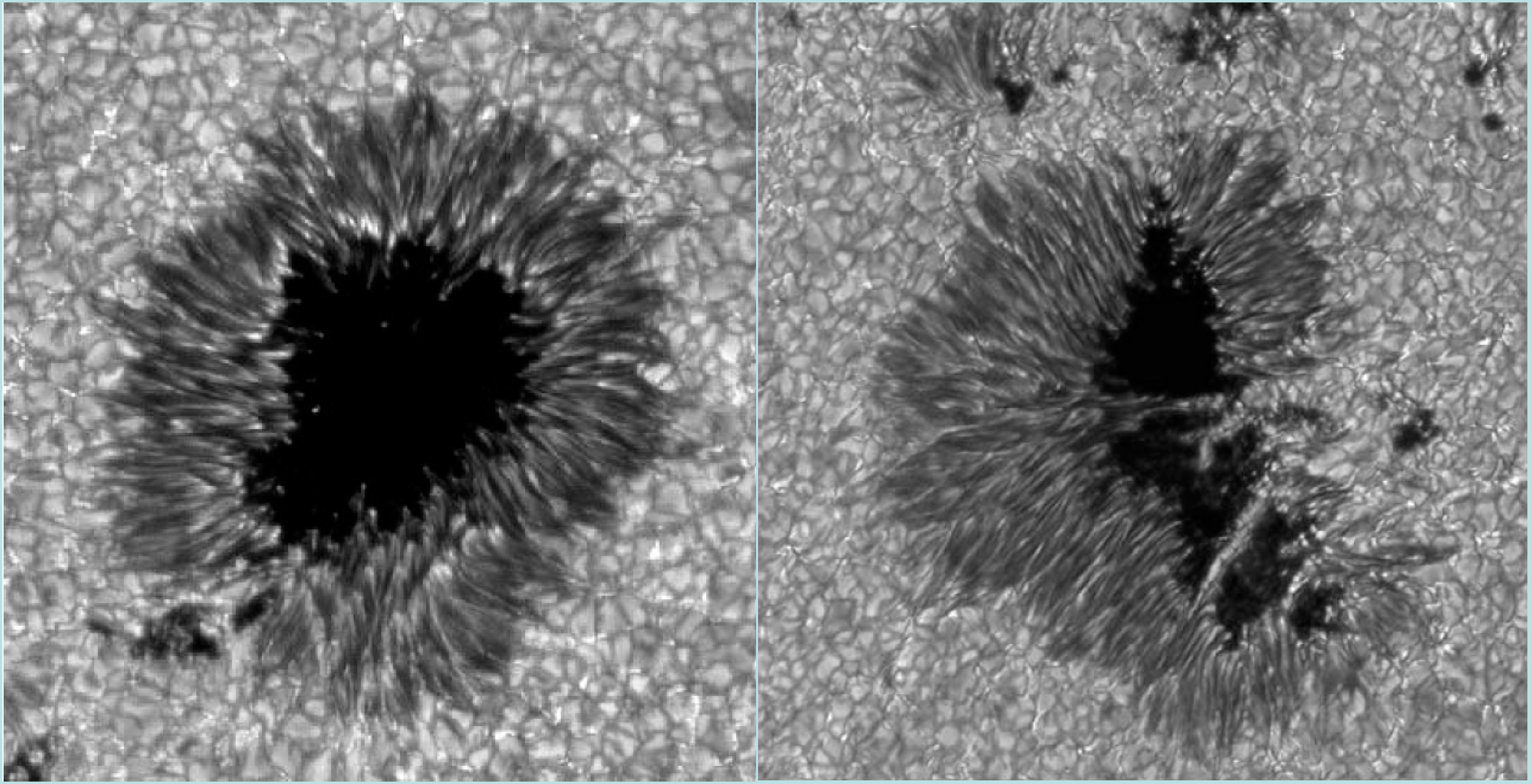
A.A. Pevtsov *et al.*, ApJ. 598 (1.12.**2003**) 1387

Coronal heating models ➔

Physical process	References
1. DC stressing and reconnection models:	
– Stress-induced reconnection	Sturrock & Uchida (1981)
	Parker (1983, 1988)
	Berger (1991, 1993)
	Galsgaard & Nordlund (1997)
– Stress-induced current cascade	Van Ballegooijen (1986)
	Hendrix et al. (1996)
	Galsgaard & Nordlund (1996)
	Gudiksen & Nordlund (2002)
– Stress-induced turbulence	Heyvaerts & Priest (1992)
	Einaudi et al. (1996a,b)
	Inverarity & Priest (1995a)
	Dmitruk & Gomez (1997)
	Milano et al. (1997, 1999)
	Aly & Amari (1997)
2. AC wave heating models:	
– Alfvénic resonance	Hollweg (1985, 1991)
– Resonant absorption	Ionson (1978, 1982, 1983), Mok (1987))
	Davila (1987), Poedts et al. (1989)
	Goossens et al. (1992, 1995)
	Steinolfson & Davila (1993)
	Ofman & Davila (1994); Ofman et al. (1994, 1995)
	Erdélyi & Goossens (1994, 1995, 1996)
	Halberstadt & Goedbloed (1995a,b)
	Ruderman et al. (1997)
	Bélien et al. (1999)
– Phase mixing	Heyvaerts & Priest (1983)
	Parker (1991); Poedts et al. (1997)
	De Moortel et al. (1999, 2000a)
– Current layers	Galsgaard & Nordlund (1996)
– MHD turbulence	Inverarity & Priest (1995b)
	Matthaeus et al. (1999)
	Dmitruk et al. (2001, 2002)
– Cyclotron resonance	Hollweg (1986), Hollweg & Johnson (1988)
	Isenberg (1990), Cranmer et al. (1999a)
	Tu & Marsch (1997, 2001a,b)
	Marsch & Tu (1997a,b,2001)
3. Acoustic heating:	Schatzman (1949)
– Acoustic waves	Kuperus, Ionson, & Spicer (1981)
4. Chromospheric reconnection:	Litvinenko (1999a)
	Longcope & Kankelborg (1999)
	Furusawa & Sakai (2000)
	Sakai et al. (2000a,b, 2001a,b)
	Brown et al. (2000)
	Tarbell et al. (1999)
	Ryutova et al. (2001)
	Sturrock (1999)
5. Velocity filtration:	Scudder (1992a,b; 1994)

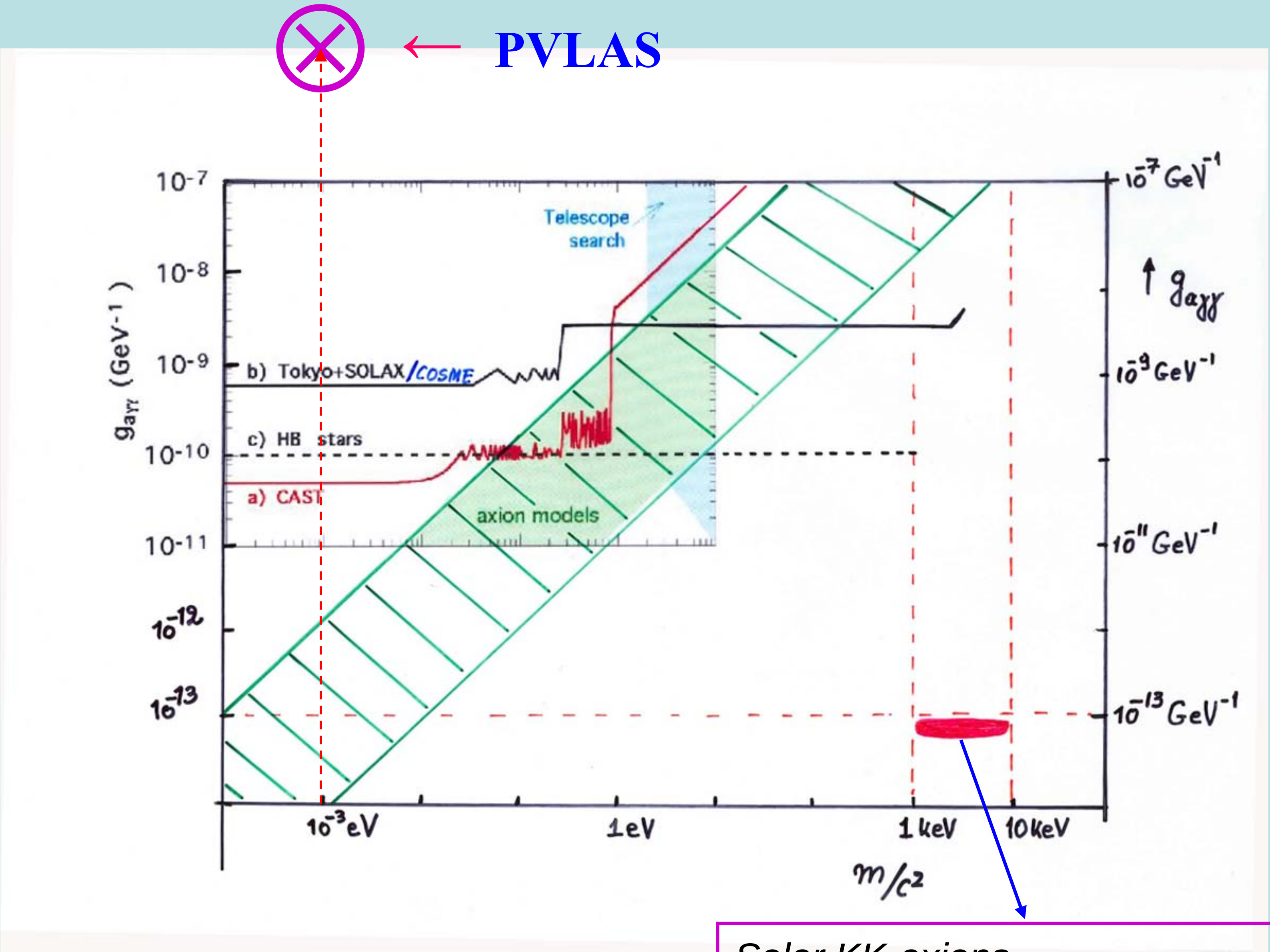
M. Aschwanden,
Physics of the Solar Corona (**2004**) p.360

Sunspots



Images recorded in a roughly 10 Å wide band centered on 4306 Å of a relatively regular sunspot (***left***) and a more complex sunspot (***right***). The central, dark part of the sunspots is the ***umbra***, the radially striated part is the ***penumbra***. The surrounding bright cells with dark boundaries are granular convection cells. Sunspot has a maximum diameter of ~30000 km (***left***), ~50000 km (***right***).

S.K. Solanki, A.&A.Rev. 11 (2003) 153



Solar KK-axions,
DiLella, Z., Astropart. Phys.19 (**2003**)145

http://www.unine.ch/phys/corpus/tpc2002/zioutas.ppt

TOTAL SOLAR IRRADIANCE → visible light

➔ ***strong evidence that the magnetic elements with higher flux are less bright.***

N.A. Krivova, S.K. Solanki,M. Fligge, Y.C. Unruh, A.&A. 399 (**2003**) L1

SOLAR X-RAYS → ~ 0.5 – 4.4 keV

➔ ***correlation between the locations of the brightest X-ray emission and the locations of bipolar magnetic active regions.***

G.H. Fisher, D.W. Longcope, T.R. Metcalf, A.A. Pevtsov, ApJ. 508 (**1998**) 885

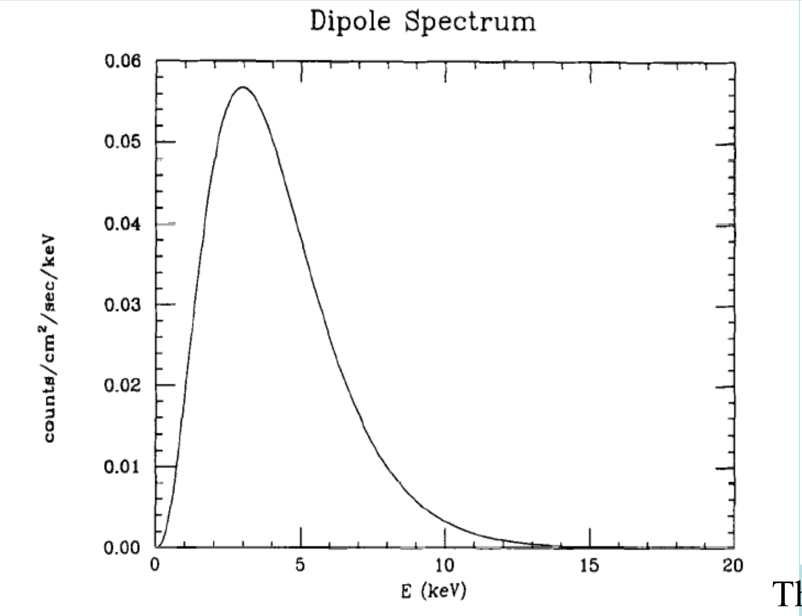
➔ ***significant correlation between the absolute magnetic field strength and X-ray emission.***

A.O. Benz, S. Krucker, L.W. Acton, T.S. Bastian, A. & A. 320 (**1997**) 993

Pseudoscalar conversion and X-rays from the sun

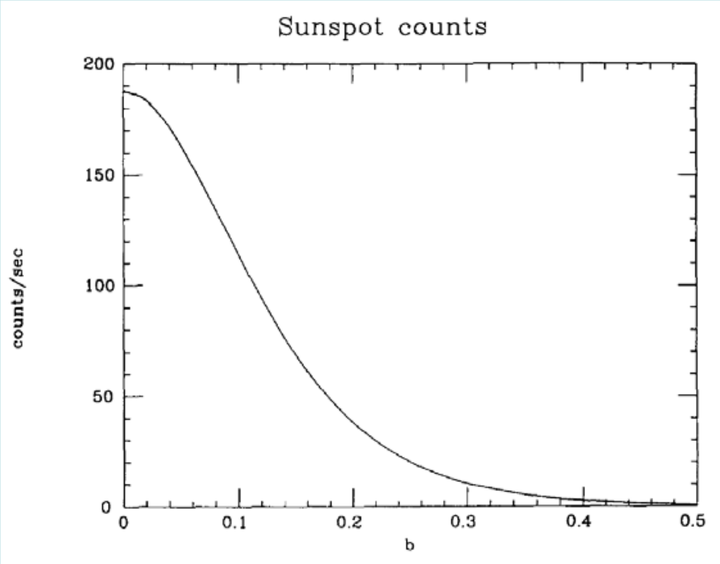
Carlson & Tseng , Phys. Lett. B 365 (1996) 193

… on the conversion of pseudoscalars produced in the sun's interior in the presence of the sun's external magnetic dipole field and sunspot-related magnetic fields. We find that the sunspot approach is superior. Measurements by the **SXT/Yohkoh** can measure the coupling constant down to $g_{a\gamma\gamma} = 0.5\text{-}1\times10^{-10}$ GeV^{-1}, provided $m < 7\times10^{-6}$ eV.



The expected X-ray signal due to pseudoscalar-photon conversion in the sun's general dipole field, taking $g_{a\gamma\gamma} = 10^{-10}$ GeV^{-1} and B_P=1 Gauss

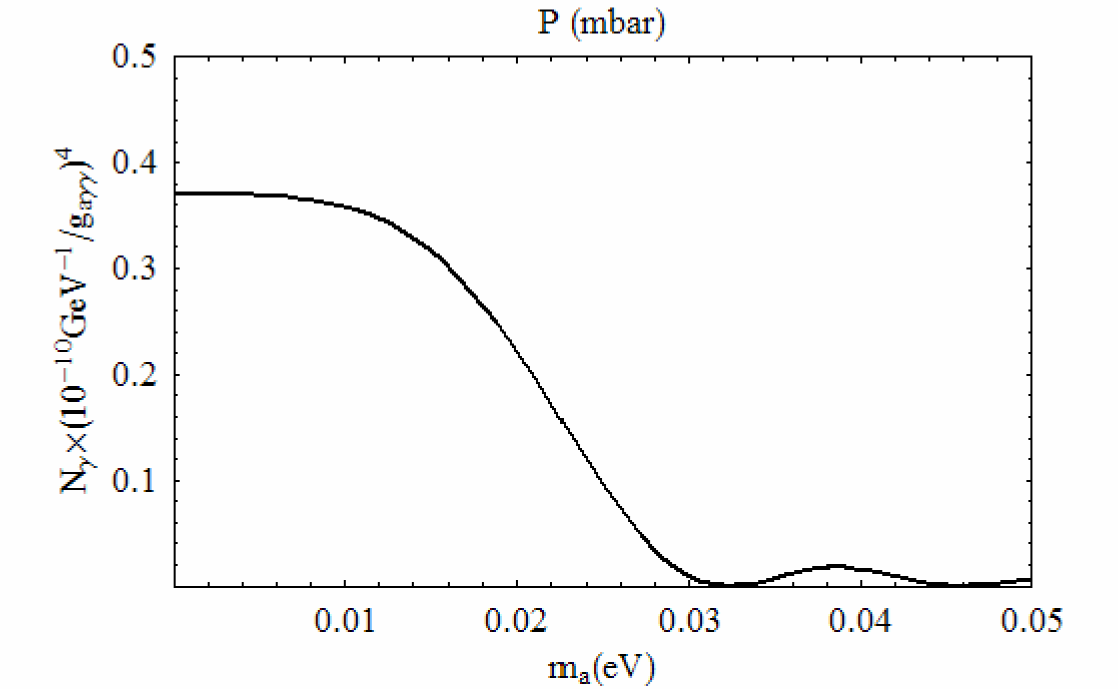
⇏ ***no significant X-ray count rate above background***



The expected X-ray count rate detected by Yohkoh's unfiltered SXT due to pseudoscalar-photon conversion in the magnetic field of a sunspot ($g_{a\gamma\gamma} = 10^{-10}$ GeV^{-1} & $\Phi=10^{23}$ maxwells). The sunspot's center defines the impact parameter bR_{solar}.

Unfortunately, the signal is dominated by background, which for such a large sunspot would be of the order of 4100 counts/s.

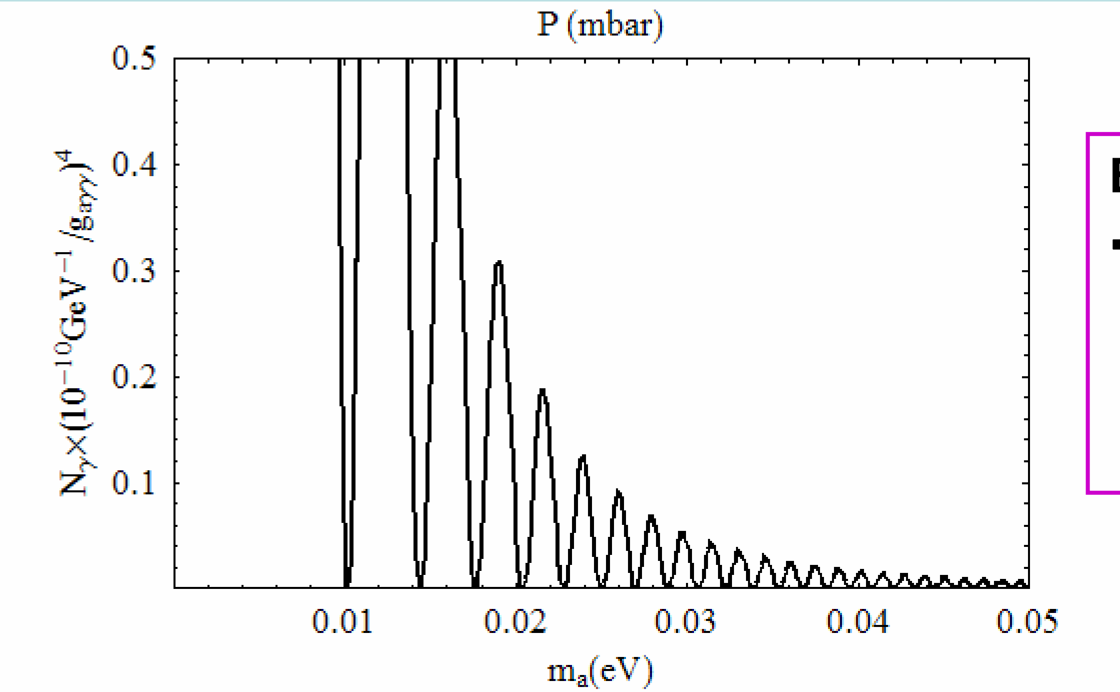
Search for ~ massless solar axions $\otimes$ $\mathbf{B}_{sun}$ ➔ **limits** for $g_{a\gamma\gamma}$ & m_{axion}



E=4.2 keV, L=10 m:

$N_\gamma(m_a=0.02 \text{ eV}) = 0.222$

$N_\gamma^{max} = 0.37$



E=4.2 keV, L=100 m:

➔ oscillations

Nγ(ma=0.02 eV) = 0.063, but

Nγ(ma=0.019 eV) =0.308

Nγmax = 37

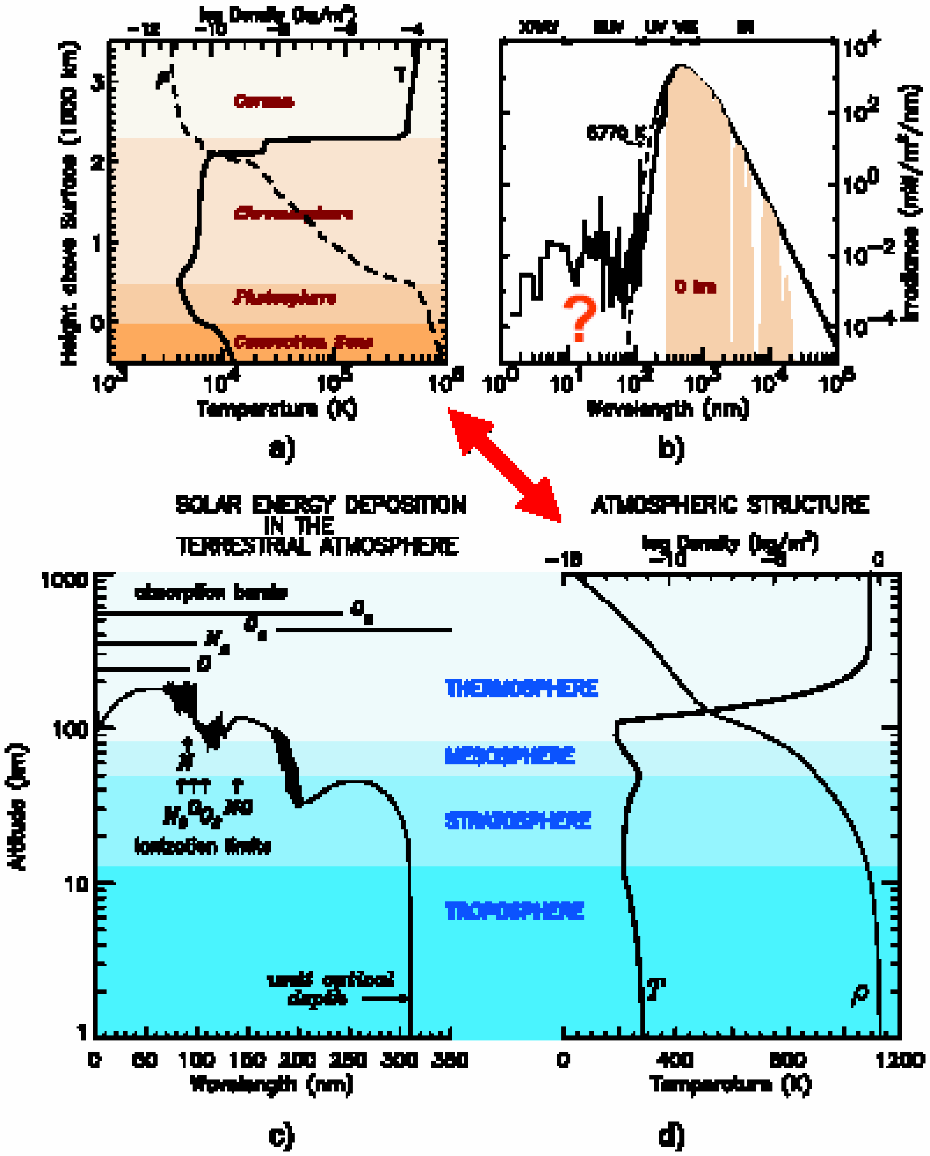
➔ Biljana LAKIC

2nd Law of Thermodynamics →

Heat transfer → hotter-to-cooler

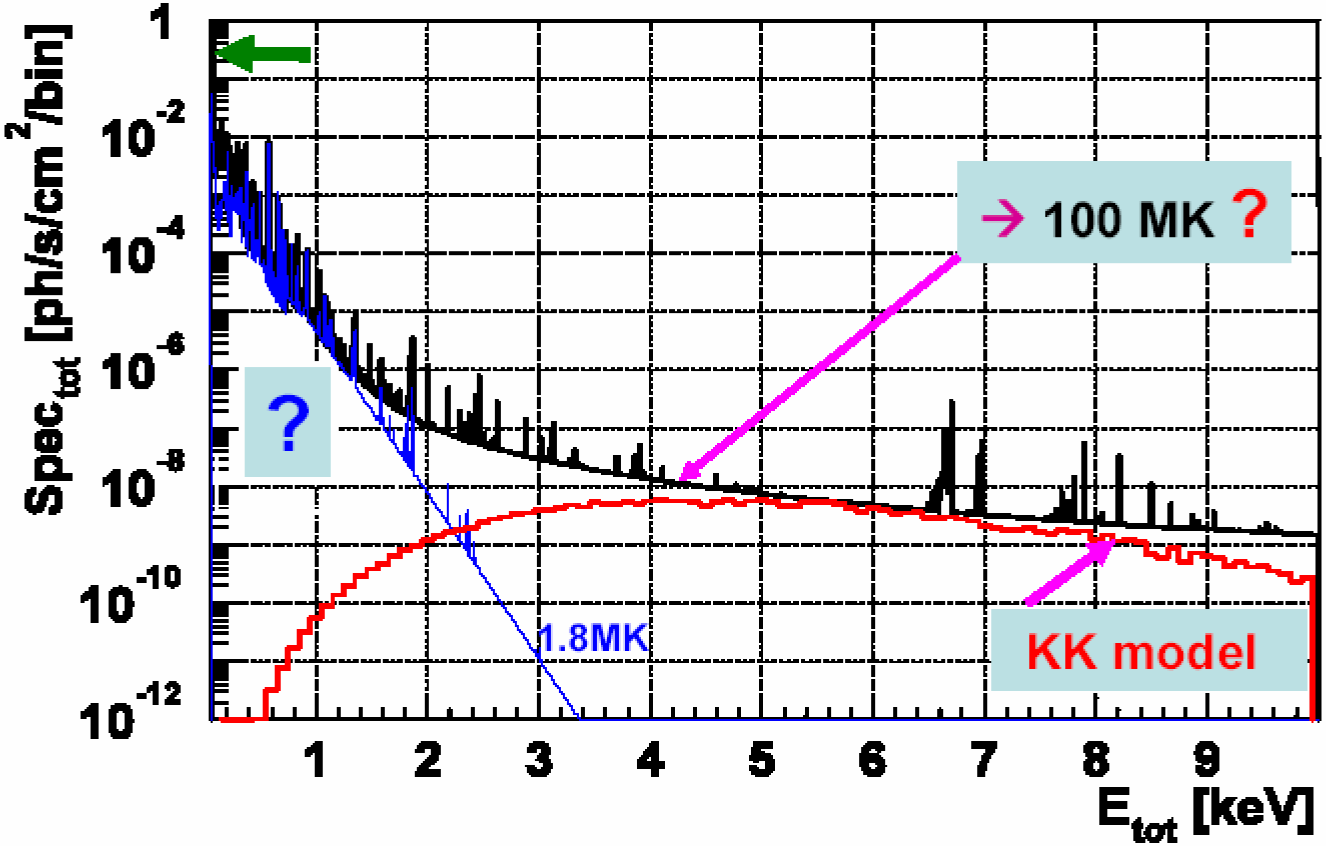
Suggestion:

→ solar X-ray
self-irradiation



L. DiLella, K. Z. Astropart. Phys. 19 (2003) 145

Observational evidence for gravitationally trapped massive axion(-like) particles



Reconstructed X-ray spectrum

➔ *non-flaring Sun @ solar minimum* [X].

KK-*axions*

↓

generic

↓

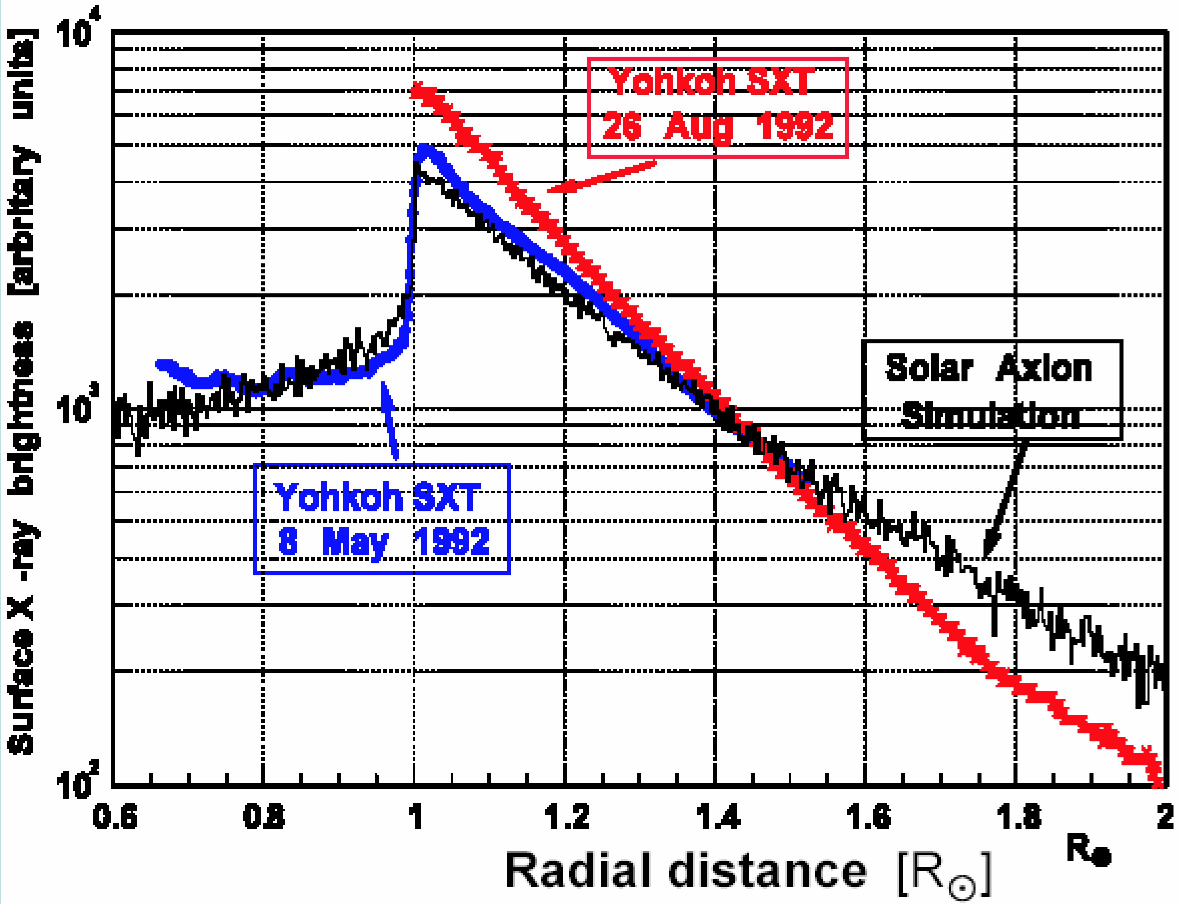
$g_{a\gamma\gamma} \sim 9 \cdot 10^{-14} GeV^{-1}$

$\bar{T}_{flare}$ < 20MK

[X] G. Peres, S. Orlando, F. Reale, R. Rosner, H. Hudson, ApJ. 528 (2000) 537

L. DiLella, K. Z., Astropart. Phys. 19 (2003) 145

Quiet Sun X-rays as Signature for New Particles



Soft X-ray surface brightness from the quiet Sun.

Simulation with trapped solar KK-axions ⟹ $g_{a\gamma\gamma} < 40 \cdot 10^{-14} GeV^{-1}$.

26 August: off-pointing
(JL Culhane, Adv. Space Res. 19 (1997) 1839)

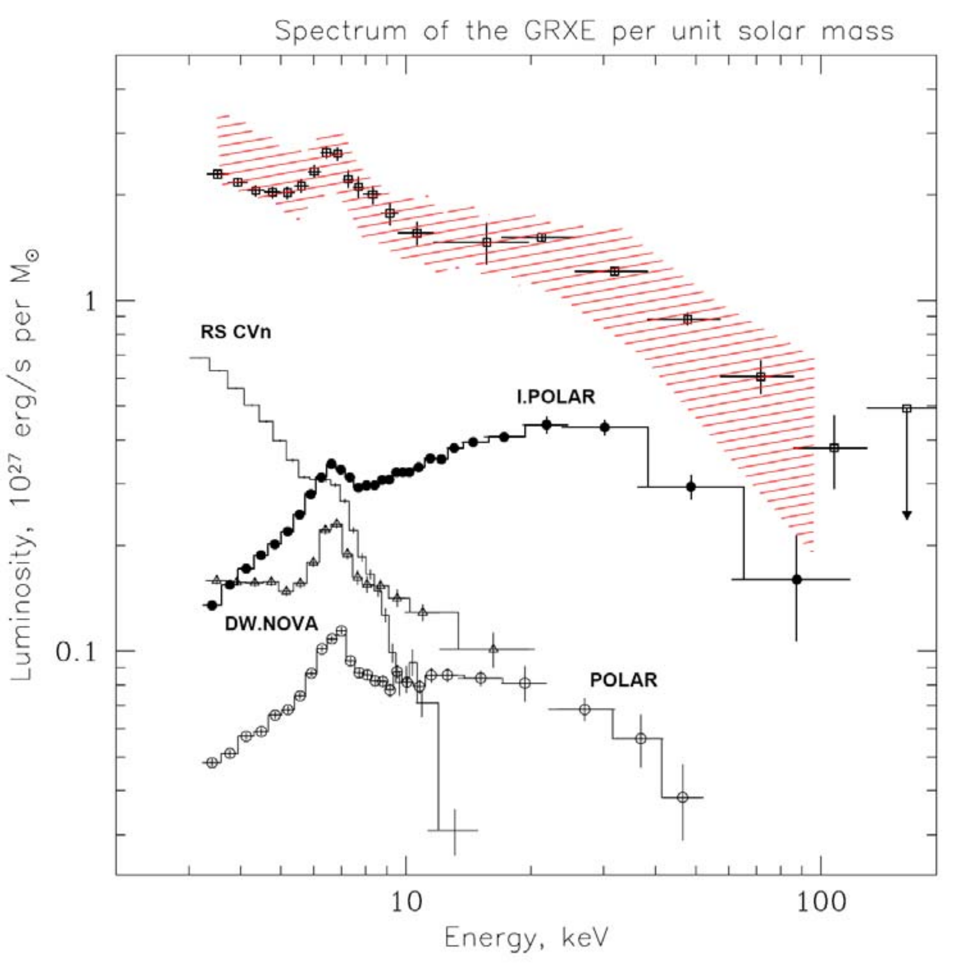
- **Diffuse emission.**
- **Hydrostatic equilibrium doesn't fit observations**
- **closed loops of increasing height … cannot reproduce the observed behaviour of T & ρ @ diffuse structure.**
- **AR emission … no strong correlation with T_{plasma} ➔**
  This suggests that the natur of coronal heating mechanis does not change through th cycle.

. . . .

- **Soft X-Ray Emission has been detected from a north polar coronal hole.**
  (see Foley, Culhane, Actor ApJ. 491 (1997) 933

Z., Dennerl, DiLella, Hoffmann, Jacoby, Papaevangelou, ApJ. 607 (**2004**) 575

Origin of the GRXE ➔ *(un)explained ?*



GRXE broad-band spectrum (squares) and spectra of its main contributors divided by 2 for clarity. The data points in the 3–20 keV band (RXTE/PCA) were converted to unit-stellar-mass emissivity. The data points in the 20–100 keV band show the spectrum of the Galactic Center source IGR J17456−2901 measured by INTEGRAL divided by the estimated total mass in stars ($\sim 10^8 M_{solar}$) contained in the nuclear region (~30 pc around Sgr A∗). The INTEGRAL spectrum was additionally multipled by a factor 0.6 to match the RXTE/PCA spectrum near 20 keV. Also shown are typical spectra of X-ray source classes expected to significantly contribute to the GRXE: intermediate polars (filled circles), polars (open circles), dwarf novae (SU UMa, triangles), and coronally active binaries. These spectra are plotted with normalizations corresponding to their expected relative contributions to the GRXE divided by 2. The individual source spectra were obtained by the instruments PCA (3–20 keV) and HEXTE (20–100 keV) aboard RXTE.

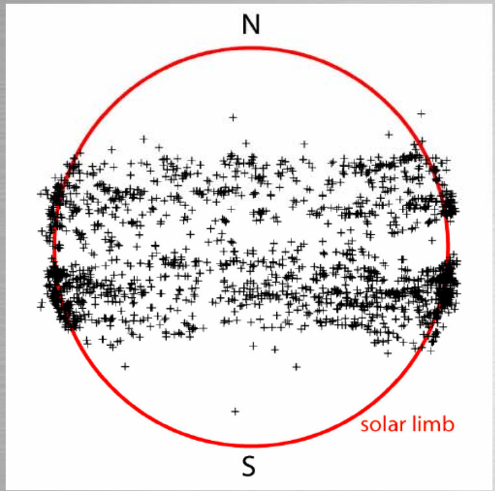
➔ **The *shaded region* shows a sum of these spectra reflecting uncertainties in the individual spectra and their relative weights.**

Mean 3-20 keV X-ray luminosity per M_{solar}

≈ (3.5±0.5) 10^{27}erg/s ≈ x$10^5 L_{x,solar}$

M. Revnivtsev, S. Sazonov, M. Gilfanov, E. Churazov, R. Sunyaev
astro-ph/200510050 ➔ A.&A.

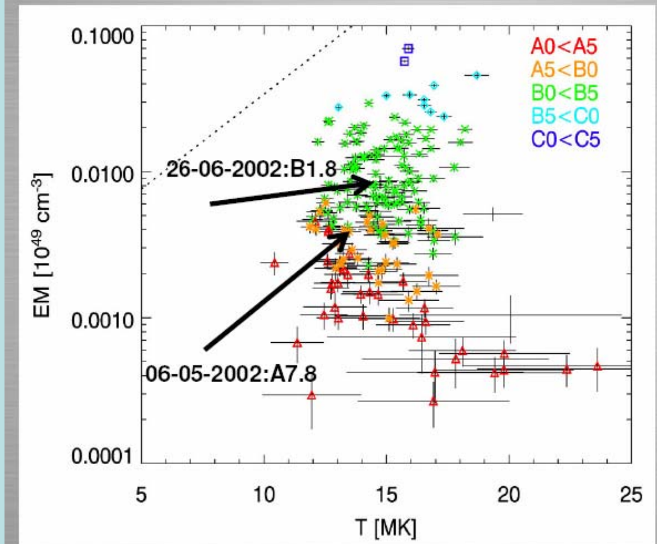
RHESSI Microflares



Rauscher et al.

- These are small flares (A-C Class), occurring in active regions
  - coronal acceleration (reconnection?)
  - heated & accelerated electrons
  - then bremsstrahlung out.
- RHESSI provides the x-ray spectrum and image of these events
  - times of shutter out and no decimation (quiet times) get about 2.5 flares per hour

T vs EM at Peak Time



Emission Measure vs Temperature at the time of peak i 3-6 keV for 199 flares.

Colour coded by background subtracted GOES class

Dotted line from Feldman et al [1996]: Average BCS T vs EM from BCS, GOES (1-8)Å and (0.5-4)Å

No clear correlation

All T >10 MK

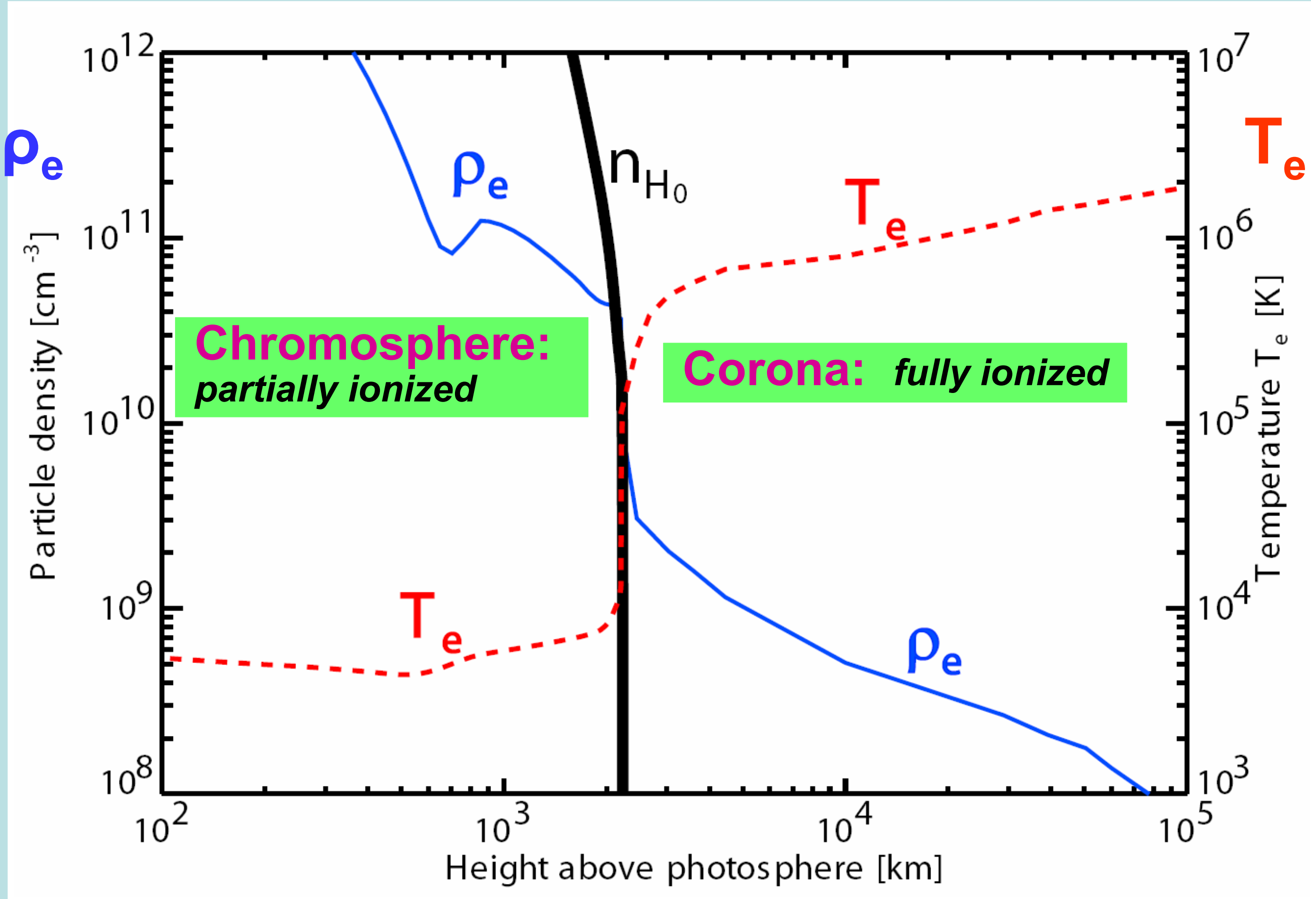
RHESSI sees higher T or lower EM

μflares are small flares that occur in active regions.

They are hot (>10 MK) with presence of Fe K Complex
Difficult to interpret thermal vs non-thermal spectrum or super-hot component.
Possibly a lot of energy in the non-thermal electrons.

Sept. **2004**

http://www.soho15.org/PDF/hannah.pdf



Electron density (ρ_e) and temperature (T_e) model of the chromosphere and the corona. The plasma becomes fully ionized at the ***sharp transition***: *)

Chromosphere → Corona

n_{H_0} = neutral hydrogen density.

***) ~100 km thick (vertical)**
(S. Patsourakos et al., ApJ. 522 (1999) 540)

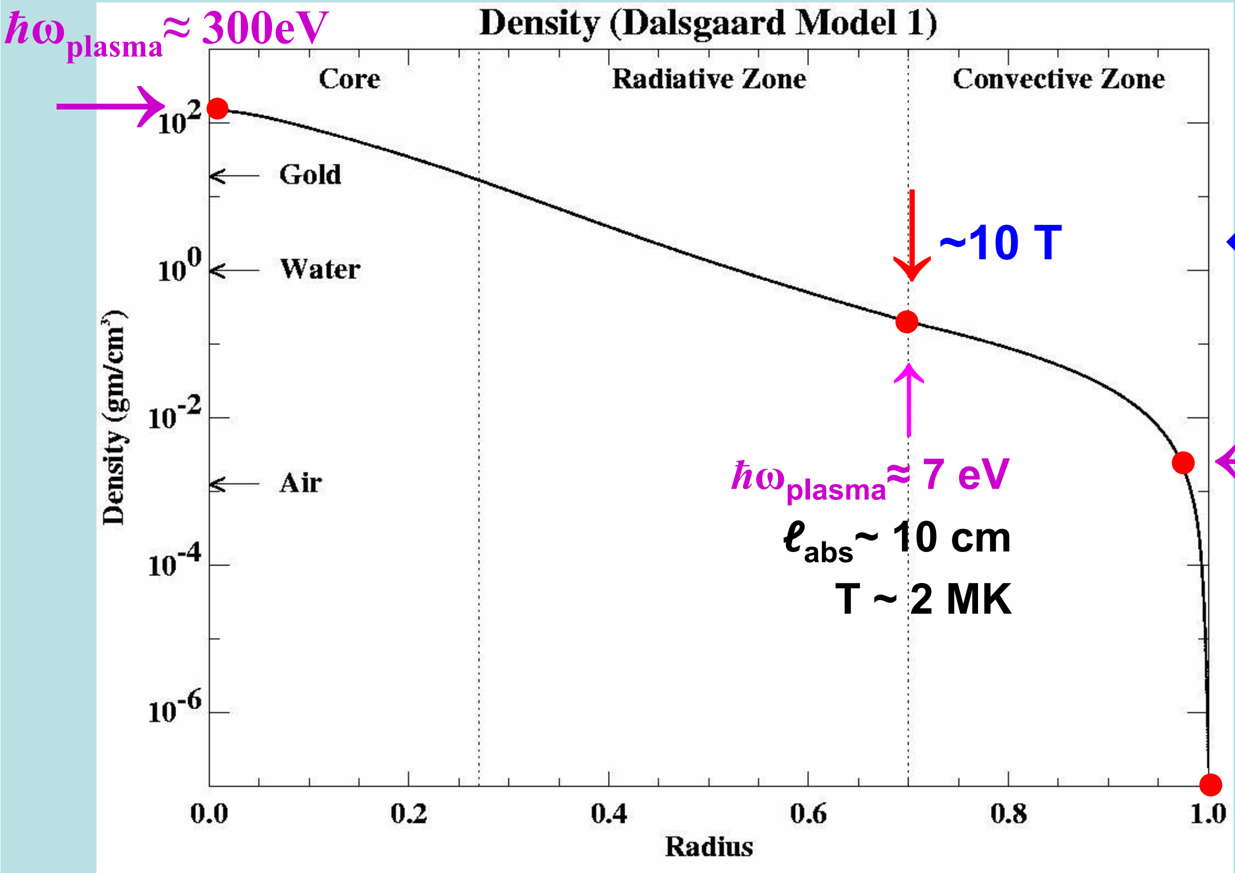
"At any given height, ρ_e varies by a factor of 10 - 100 over the entire corona." …

"The physical understanding of this high temperature in the solar corona is still a **fundamental problem in astrophysics**, because it seems to violate the **second thermodynamic law**, given the photospheric temperature T≈5785K (and drops to T~4500K in **sunspots**)." M. Aschwanden, *Physics of the Solar Corona* (**2004**) p.24-26

Photosphere: **only ~0.1% of the gas is ionized** (= plasma).

http://www.windows.ucar.edu/tour/link=/sun/atmosphere/photosphere.html

The inner SUN



M. Schüßler, M. Rempel A.&A. (**2005**), astro-ph/0506654 **#)**

$\hbar\omega_{plasma} \approx$ 1eV → -20000 km

ℓ_{abs}~20 m

$\hbar\omega_{plasma} \approx 10^{-2}$eV → surface

ℓ_{abs}~100 km

If $\hbar\omega_{plasma} \approx m_{axion}c^2$ → **~ resonance crossing**

→ $(\text{Primakoff})_B$ >> $(\text{Primakoff})_{\text{Coulomb}}$

→ **New solar axion spectrum?**

http://science.msfc.nasa.gov/ssl/pad/solar/interior.htm

#) also: M. Aschwanden, *Physics of the Solar Corona* (**2004**)175